# BWZee

# A biological valuation map for the Belgian part of the North Sea

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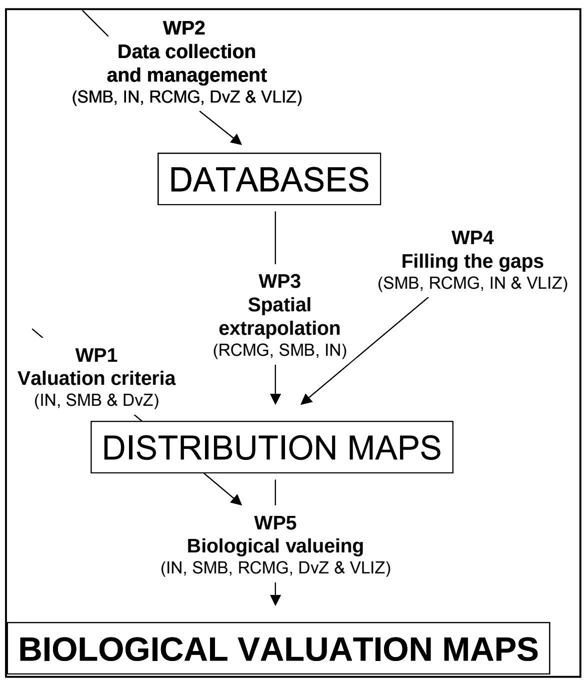
## INTRODUCTORY NOTE

The Belgian part of the North Sea (BPNS) is one of the most exploited areas of the North Sea and this necessitates more sustainable use of its resources and space. Policy makers are becoming more and more aware of this fact but to be able to implement sustainable policy actions they need baseline maps showing the intrinsic biological value of the different subzones within the BPNS. Due to the lack of such maps in the past they based their policy actions (e.g. implementations of windmill farms, site selection for sand extraction,…) on the expert judgement of scientists and stakeholders. Having these maps which compile integrated biological knowledge will allow them to avoid the most valuable sites of the area during future spatial planning activities.

The aim of the BWZee project was to provide such baseline biological valuation maps. These maps compile as much biological information as is available at this time. Different ecosystem components were taken into account when constructing the final biological valuation map of the BPNS: seabirds, macrobenthos, hyperbenthos, epibenthos and demersal fish. For other ecosystem components (e.g. sea mammals, pelagic fish,…) the available data were too sparse or too fragmentary dispersed at the initial phase of the project. This final report represents the results of the project and these results were only possible through a close collaboration of different institutes. The scheme below gives an overview of the different tasks within the project and the institutes that were involved in these tasks:




A broad multidisciplinary expertise within the partner consortium was a *condition sine qua non* to be able to reach the final goals of this project. Therefore, each of the partners brought in its own complementary expertise into the project:

- Marine Biology Section of the University of Gent (SMB) – Sofie Derous, Marijn Rabaut, Magda Vincx & Steven Degraer: Macrobenthos, habitat suitability mapping
- Research Institute for Nature and Forest (INBO) – Wouter Courtens & Eric Stienen: Seabirds, (terrestrial) biological valuation, GIS
- Renard Centre of Marine Geology of the University of Gent (RCMG) – Els Verfaillie & Vera Van Lancker: Habitat characterization, spatial extrapolation, GIS

- Institute for Agricultural and Fisheries Research (ILVO) – Ine Moulaert & Kris Hostens: Epibenthos, demersal fish
- Flanders Marine Institute (VLIZ) – Daphne Cuvelier, Pieter Deckers, Klaas Deneudt, Ward Vanden Berghe & Jan Mees: Data management, GIS, dissemination

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# I. Introduction

The continuously increasing socio-economical interest in marine resources urges the need for a decision making framework to objectively allocate the different user functions at the Belgian Part of the North Sea (BPNS). This calls for a spatial structure plan, preferentially firmly based on the concept of integrated marine management, in which biological value should be carefully taken into account. Unfortunately, so far an integrated view on the biological value of the BPNS is lacking. A first attempt to assess the biological value of (parts of) the BPNS exists, but this study only took into account one ecosystem component (i.e. macrobenthos) and non-extrapolated to the whole shelf, generally failing to provide an integrated, full-coverage Biological Valuation Map of the BCS.

Since no marine biological valuation map has been set up in other parts of the world yet, a novel approach was searched for. The generation of the biological valuation map for Belgian marine waters was therefore initially based on the experience acquired during the actualisation of the terrestrial valuation maps. During a first workshop (May 2004) the applicability of the methodology of the terrestrial valuation maps in marine waters was discussed with the terrestrial experts and information was gathered on the possible pitfalls during such valuation process. Because of fundamental differences between the terrestrial and marine ecosystem structure and functioning it was needed to hold an international workshop (December 2004) where experts in terrestrial biological valuation, marine biology experts and marine policy advisers searched for an adapted approach for the biological valuation of the BPNS. A first literature review prior to this meeting listed a whole range of valuation criteria circulating in academic and grey literature. There seemed to be much redundancy in valuation criteria and methods and these were screened at the international workshop and the most suitable biological valuation criteria were selected for further implementation in the valuation methodology. A concept for the biological valuation of marine waters was delineated with emphasis on its general applicability in different ecosystems and on its scientific acceptability.

The marine biological valuation map should include and integrate information on all marine ecosystem components for which detailed spatial distribution data are available. At the BPNS such data are primarily available for the macrobenthos and seabirds (macrobenthos: UGent-MACRODAT database; seabirds: IN database) for which full-coverage maps can be constructed. To a lesser extent, but still useful from a valuing perspective, data on the spatial distribution of the demersal fish and the epi- and hyperbenthos exist (UGent and DVZ databases). It was decided to create full-coverage biological valuation maps of the BPNS using the spatial distribution of macrobenthos communities and seabird data, while demersal fish and epi- and hyperbenthos data should be used as point data only allowing these ecosystem components to be valued on these points. However, due to a lack of time and expert knowledge on the matter, it was decided during the last phase of the project to exclude hyperbenthos data from the analysis.

The seabird database consists of a set of points where densities are known. In order to cover the entire Belgian marine area a GIS-aided inter- and extrapolation was performed. Contrary to avifauna data, in which direct observations almost provide full-coverage information for numerous areas at the BPNS, benthos data should be regarded as point data. To spatially extrapolate these point data, needed to obtain a full coverage spatial distribution map, a predictive model, based on the close link between the macrobenthos communities and their physical habitat, was set up. Once this model was developed and validated, the model enables to extrapolate the spatial distribution of the macrobenthos communities to the full BPNS, using existing data on the physical habitat (GIS-aided).

In a next step a valuation protocol was set up around the selected biological valuation criteria allowing them to be practically assessed using the available data (whether they cover the entire BPNS or not). This was done by creating a set of assessment questions for each criterion and by choosing an appropriate scoring system to integrate the scores of the different assessment questions. Applying this protocol to the data allows producing a marine biological valuation map for the BPNS which integrates all available biological information for different ecosystem components. This map clearly shows where the biologically most valuable, the medium valuable and the least valuable subzones are located in the BPNS. Attached to this information is a statement of the reliability of the obtained biological value (based on information on the available data, sampling errors or other factors).

The marine biological valuation map is an indispensable tool to obtain an objective and scientifically-sound spatial structure plan of the BPNS. Next to the above mentioned exploitation of the final result of BWZee, other results are:
(1) an integrated databases on the biology and physical environment of the BCS
(2) the innovative approach to set up a marine biological valuation map (e.g. valuation criteria)
(3) the development of the habitat-based predictive model
(4) full coverage information on the spatial distribution of macrobenthos and seabirds at the BCS
(5) the translation of results and conclusions for the benefit of scientists, managers, policy makers, the public at large.

# II. Selection of marine valuation criteria

The following article, accepted for publication in the journal Oceanologia, is a direct end result of the BWZee project and gives an overview of the selection of marine valuation criteria.

Sofie Derous, Tundi Agardy, Hans Hillewaert, Kris Hostens, Glen Jamieson, Louise Lieberknecht, Jan Mees, Ine Moulaert, Sergej Olenin, Desiré Paelinckx, Marijn Rabaut, Eike Rachor, John Roff, Eric Stienen, Jan Tjalling van der Wal, Vera Van Lancker, Els Verfaillie, Magda Vincx, Jan Marcin Weslawski, Steven Degraer (in press). ***A concept for biological valuation in the marine environment.*** Oceanologia.

### *A. ABSTRACT*

In order to develop management strategies for sustainable use and conservation in the marine environment, reliable and meaningful, but integrated ecological information is needed. Biological valuation maps that compile and summarize all available biological and ecological information for a study area, and that allocate an overall biological value to subzones, can be used as baseline maps for future spatial planning at sea. This paper provides a concept for marine biological valuation which is based on a literature review of existing valuation criteria and the consensus reached by a discussion group of experts.

### *B. INTRODUCTION*

There is a worldwide recognition of the benefits of management for sustainable use and conservation of the sea (e.g. Tunesi and Diviacco, 1993; Vallega, 1995; Ray, 1999; EC Habitat and Bird Directives; proposed Marine Strategy Directive). Solid and meaningful biological and ecological information is urgently needed to inform and underpin sustainable management approaches. Biological valuation maps (BVMs), i.e. maps showing the intrinsic biodiversity value of subzones within a study area, would provide a useful “intelligence system” for managers and decision makers. Such maps would need to make best use of available data sets, compiling and summarizing relevant biological and ecological information for a study area, and allocating an overall biological value to different subzones. Rather than a general strategy for protecting areas that have some ecological significance, biological valuation is a tool for calling attention to areas which have particularly high ecological or biological significance and to facilitate provision of a greater-than-usual degree of risk aversion in management of activities in such areas.

Biological valuation assessments have been developed primarily for terrestrial systems and species (De Blust et al., 1985; 1994). The relevance of terrestrial approaches in determining specific valuation criteria for marine systems requires an understanding of both the nature and degree of differences between marine and terrestrial systems (e.g. the extent and rate of dispersal of nutrients, materials, planktonic organisms and reproductive propagules of benthic organisms, expanding the scales of connectivity among near-shore populations, communities and ecosystems (Fairweather and McNeill, 1993; Carr et al., 2003); and seasonal variation (Ray, 1984)). Concepts for the selection of valuable offshore marine areas must therefore consider the ‘openness’ (continuity and natural coherence) of the sea (Rachor and Günther, 2001).

Problems encountered when applying terrestrial-based assessments to marine areas are currently demonstrated in the difficulties encountered implementing the EC Habitats Directive (92/43/EEC) in the marine environment. The Directive was written from a terrestrial viewpoint, and applying it to more dynamic marine systems proved problematic (Hiscock et al., 2003). Criteria developed for identifying terrestrial species and habitats for conservation cannot be easily applied to the marine environment. Therefore different valuation criteria may be needed for marine areas (see Fairweather and McNeill, 1993; Carr et al., 2003). The European Commission is currently developing a Marine Strategy Directive which recognizes the need of a thematic strategy for the protection and conservation of the European marine environment with the overall aim to promote sustainable use of the seas and conserve marine ecosystems. This Directive is written from a marine viewpoint and was driven by the fact that no integrated policy focused on the protection of the European marine environment. It is still in its developmental phase but one of its goals will be the determination of good environmental status (for habitat types, biological components, physico-chemical characteristics and hydromorphology) of the marine waters by 2021 (CEC, 2005). The criteria and standards to determine this good environmental status will only be determined once the Directive is in force, so it could be appropriate to use the same biological valuation criteria (at least for the biological elements covered by the proposed Directive) as selected below in this paper, to have better agreement amongst these initiatives.

Coastal planners and marine resource managers have utilized various tools for assessing the biological value of subzones in the past. These approaches vary in information content, scientific rigour, and level of technology used. The most simple approach is a low-tech participatory planning which occurs often in community-based marine protected area (MPA) design (e.g. the Mafia Island Marine Park Plan described in Agardy, 1997), but the selection of such priority areas is very ad-hoc, opportunistic, or even arbitrary, resulting in decisions which are often difficult to defend to the public. The chance of selecting the areas with the highest intrinsic biological and ecological value through these methods is small (Fairweather and McNeill, 1993; Ray, 1999; Roberts et al., 2003b). Later on, a more Delphic-judgmental approach has been advocated. In this approach, an expert-panel is consulted to select areas for protection, based on expert knowledge. The method is relatively straightforward and easily explained, which may indicate why it is still common (Roberts et al., 2003b). However, due to the urgency for site selection, the consultation process is usually too short, the uncertainty surrounding decisions is too high and the information input is too generalized to permit defensible, long-term recommendations (Ray, 1999). The disadvantages of these aforementioned existing methods for assessing the value of marine areas have led to an increasing awareness that a more objective valuation procedure is needed. Other existing methodologies utilize a variety of tools to optimize site selection through spatial analysis, such as Geographic Information System (GIS)-based multicriteria evaluation (e.g. Villa et al., 2002). The most sophisticated methods are these where planning is driven in part by high-tech decision-support tools. One such tool is MARXAN, which is a systematic conservation planning software program used to identify reserve designs that maximize the number of species or communities contained within a designated level of representation. The methodology behind this approach is described by Possingham et al. (2000), and it has been incorporated into various planning efforts (e.g. the zoning of the Great Barrier Marine Park as per Pressey et al., 1997). This technique is mostly used for reserve selection and uses mathematical models to select those subzones which contribute most to the specified conservation goals established for the system while minimizing the costs for conservation (Stewart and Possingham, 2002; Airamé et al., 2003; Lieberknecht et al., 2004b; Lourie and Vincent, 2004; Fernandes et al., 2005). Without denying the merits of MARXAN and similar mathematical tools for conservation planning, this technique cannot be applied for the purpose of biological valuation of an area. Biological valuation is not a process to select areas for conservation according to quantitative objectives, but gives an overview of the integrated biological value of the different subzones within a study area (relatively to each other). The decision to include of one or more subzones in a marine reserve cannot be made based on the outcome of a biological valuation, because the latter process doesn't take into account management criteria and quantitative conservation targets.

The common element of all approaches mentioned above is the identification of criteria to discriminate between marine areas and guide the selection process; and whilst the vast majority of these efforts pertain to marine protected area design, there is no reason why such criteria cannot be equally helpful in coastal zone and ocean management more generally.

It is therefore necessary that the definition of the value of marine areas should be based on the assessment of areas against a set of objectively chosen ecological criteria, making best use of scientific monitoring and survey data (Mitchell, 1987; Hockey and Branch, 1997; Ray, 1999; Connor et al., 2002; Hiscock et al., 2003). A first step towards such an objective valuation framework was recently made in the Netherlands where selection criteria from the EC Habitat (92/43/EEC) and Bird (79/409/EEC) Directives and the OSPAR guidelines (OSPAR, 2003) were used in order to determine which marine areas have special ecological values in terms of high biodiversity (Lindeboom et al., 2005).

This paper aims at developing a scientifically sound and widely applicable concept for marine biological valuation, drawing on existing valuation criteria and methods (literature review) and attempting to rationalize them into a single model. This concept represents a consensus reached by a large and diverse group of experts in the field (see author list) during a workshop on marine biological valuation (2-4 December 2004, Ghent, Belgium). Next to its immediate merit as a guideline for marine biological valuation, this paper can also be regarded as an incentive to further discussion on marine biological valuation.

## *C. DEFINITION OF MARINE BIOLOGICAL VALUE*

Different definitions of 'marine biological value' are currently found in the literature. What is meant by 'value' is directly linked to the objectives behind the process of valuation (e.g. conservation, sustainable use, preservation of biodiversity, etc.). Discussions on the value of marine biodiversity almost always refer to the socio-economic value of biodiversity (i.e. the so-called value of the goods and services provided by marine ecosystems, or the value of an area in terms of importance for human use), and attempts to attach a monetary value to the biodiversity in an area (Bockstael et al. 1995, King 1995, Edwards & Abivardi 1998, Borgese 2000, Nunes & van den Bergh 2001, de Groot et al. 2002, Turpie et al. 2003). Many approaches try to highlight only the most important sites in a region in order to designate priority sites for conservation. These priority sites are often chosen on the basis of the hotspot approach, which is used to select sites with high numbers of rare/endemic species or high species richness (e.g. Myers et al. 2000, Beger et al. 2003, Breeze 2004).

For the purpose of this paper, 'marine biological value' was defined as follows: 'the intrinsic value of marine biodiversity, without reference to anthropogenic use'. This definition is similar to the definition of value of natural areas of Smith & Theberge (1986): 'the assessment of ecosystem qualities *per se*, regardless of their social interests' (i.e. their intrinsic value). By 'ecosystem qualities' the authors of the latter paper covered all levels of biodiversity, from genetic diversity to ecosystem processes.

The purpose of marine biological valuation is to provide subzones within the target study area with a label of their intrinsic biological value (on a continuous or discrete value scale, e.g. high, medium and low value). Subzones are defined as subregions within the study area that can be scored relative to each other, against a set of biological valuation criteria. The size of these subzones depends on the size of the study area, on the biodiversity components under consideration and on the amount of available data and should therefore be decided on a case by case basis. In contrast to the hotspot approach (i.e. identification of priority areas for conservation), we do not want to highlight solely the most valuable subzones. The product of the valuation process, i.e. the intrinsic values of the subzones, can then be presented on marine BVMs. The BVM can serve as a baseline map showing the distribution of complex biological and ecological information.

## *D. SELECTED VALUATION CRITERIA*

Several initiatives to select biological criteria and to develop valuation methods already exist in literature. These were reviewed (see Annex A) and the most appropriate criteria were selected for incorporation into our system. Some of these criteria have already been assessed for their applicability, and some are included in international legislation (e.g. EC Habitat -92/43/EEC- and Bird -79/409/EEC- Directives) (Brody, 1998). This latter point is very important, because any workable valuation assessment for marine areas should ideally mesh with relevant international protection or management initiatives (such as OSPAR, 1992), in so far as is practical. This may maximize consistency of approach through the territorial waters, continental shelf and superjacent waters where initiatives overlap (Laffoley et al., 2000b).

Three distinct types of literature were included in our review: articles on the assessment of valuable ecological marine areas, literature on selection criteria for Marine Protected Areas (MPAs), and international legislative documents which include selection criteria (EC Bird/Habitat Directives, Ramsar Convention, OSPAR guidelines, UNEP Convention on Biological Conservation, etc.). Only ecological criteria were considered relevant to this study, others (e.g. socio-economic or practical considerations) were not included in the overview.

Sullivan Sealey and Bustamante (1999) described a set of indicators which are indirect or direct measures of biological and ecological value and, whose assessment allows a ranking of the marine study area into subzones with different values. Following this first step, they applied a subsequent set of prioritizing criteria to the list of high-ranked areas to identify the priority areas for conservation. The criteria used to determine the conservation need of the area were based on changes induced by human activities, an evaluation of the potential threats to the area, and the political and public concern to protect the area and the feasibility of designation. The objective of our work is the same as for the first step of Sullivan Sealey and Bustamante's work (i.e ranking of areas according to their inherent biological and ecological value), but we do not address issues of determination of conservation status, or the socio-economic criteria since these also involve social and management decisions. The methodology used by these authors could not be used here since they scored the different valuation criteria through expert judgement. Here, it is tried to establish a valuation concept which is as objective as possible.

The valuation concept was developed, based in part on a framework developed for the identification of Ecologically and Biologically Significant Areas (EBSAs) (DFO, 2004; Glen Jamieson, *pers. comm.*), using five criteria: uniqueness, aggregation, fitness consequences, resilience and naturalness. The first three criteria were considered the first-order (main) criteria to select EBSAs, while the other two were used as modifying criteria to upgrade the value of certain areas when they scored high for these criteria.

It was decided that for the marine biological valuation concept presented here the criterion of 'resilience' (degree to which an ecosystem or a part/component of it is able to recover from disturbance without major persistent change, as defined by Orians (1974)) should not be included as it is closely related to the assessment of (future) human impacts, which is not an appropriate criterion for determining the current and inherent biological value of an area (although it is an important consideration in formulating practical management strategies). Of course resilience can also be an intrinsic quality of a certain biological entity to be able to resist or to recover from natural stresses (e.g. resilience of mangrove communities to climate change stress), but due to the use of the term resilience for resistance of both natural and anthropogenic stresses, it is excluded as an ecological valuation criterion. In contrast, we decided that the criterion ‘naturalness’ should be retained because it is an index of the degree to which an area is currently (though not inherently) in a pristine condition. In this way, unaltered areas with a high degree of resilience against natural stresses will still be covered by the valuation concept. The criterion ‘uniqueness’ was renamed ‘rarity’ as this term is more frequently used in literature, and it encompasses unique features.

The criteria listed in the review were then cross-referenced with the selected valuation criteria, i.e. rarity, aggregation, fitness consequences, and naturalness, to see if additional criteria needed to be included in order to produce a comprehensive valuation concept for the marine environment. It was found that there is much redundancy in valuation criteria and that most, but not all, of the criteria that are mentioned in literature are accounted for by the selected valuation criteria. One additional criterion was added to the framework, to make it fully comprehensive: ‘proportional importance’ (included as a modifying criterion). The concept of ‘biodiversity’ (including all organizational levels of biodiversity - from the genetic to the ecosystem level, separated into biodiversity structures and processes) should also be included in the valuation framework, however not as a criterion (see below). Table 1 gives an overview of the chosen set of valuation criteria together with a brief definition of each, and the upper part of Figure 1 shows an overview of the biological valuation concept proposed in this paper. Each criterion is defined and discussed in further detail in the text below. In summary, the valuation criteria selected for the development of marine BVMs are: rarity, aggregation, fitness consequences (main criteria), naturalness and proportional importance (modifying criteria).

**Table 1: Final set of marine valuation criteria and their definitions**

| Valuation criterion | Definition | Source |
|---|---|---|
| ***1st order criteria*** | | |
| Rarity | Degree to which an area is characterized by unique, rare or distinct features (landscapes/habitats/ communities/species/ecological functions/ geomorphological and/or hydrological characteristics) for which no alternatives exist. | DFO (2004); Rachor and Günther (2001), modified and complemented after Salm and Clark (1984), Salm and Price (1995) and Kelleher (1999); UNESCO (1972) |
| Aggregation | Degree to which an area is a site where most individuals of a species are aggregated for some part of the year or a site which most individuals use for some important function in their life history or a site where some structural property or ecological process occurs with exceptionally high density. | DFO (2004) |
| Fitness consequences | Degree to which an area is a site where the activity(ies) undertaken make a vital contribution to the fitness (= increased survival or reproduction) of the population or species present. | DFO (2004) |
| ***Modifying criteria*** | | |
| Naturalness | The degree to which an area is pristine and characterized by native species (i.e. absence of perturbation by human activities and absence of introduced or cultured species). | DFO (2004); Department for Environment, food and Rural Affairs (2002); Connor *et al.* (2002); JNCC (2004); Laffoley *et al.* (2000b) |
| Proportional importance | Global importance: proportion of the global extent of a feature (habitat/seascape) or proportion of the global population of a species occurring in a certain subzone within the study area. | Connor *et al.* (2002); Lieberknecht *et al.* (2004a, 2004b) |
| | Regional importance: proportion of the regional (f.i. NE Atlantic region) extent of a feature (habitat/seascape) or proportion of the regional population of a species occurring in a certain subzone within the study area. | Connor *et al.* (2002); Lieberknecht *et al.* (2004a, 2004b) |
| | National importance: proportion of the national extent of a feature (habitat/seascape) or proportion of the national population of a species occurring in a certain subzone within territorial waters. | BWZee workshop definition (2004) |

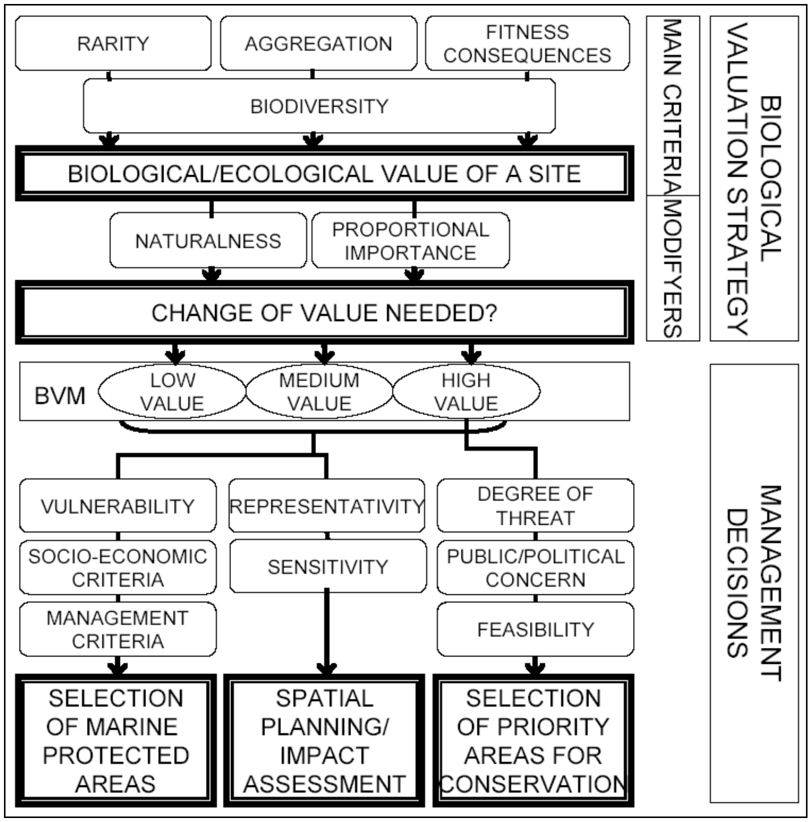


**Figure 1: Overview of the concept of marine biological valuation and possible future steps to develop decision support tools.**

## 1. Rarity

Rarity can be assessed on different scales e.g national, regional, global. In order to be able to assess rarity of marine species or communities on a regional or global scale, international lists of rare species, habitats or communities are needed. Unlike the terrestrial environment, however, very few marine species are included in Red Data Books, like the IUCN Red Lists or the appendices of CITES, CMS (RAMSAR COP 7, 1999) and the Bern Convention (1979). This is due to the lack of systematic assessment and study of marine species at a regional scale (Sanderson, 1996a, 1996b; Ardron et al., 2002). It should be noted that most species or communities that are mentioned on lists as mentioned above are 'rare' because their numbers have been depressed by human actions while other species or communities are just innumerous. For the purpose of this paper both types of rare species/communities are considered. If such rare species lists on a local or regional scale are not available, species rarity within a subzone can still be assessed if data on their population size (at a national or regional scale) and trends are available. Population data are frequently lacking, which only leaves the 'area of occupancy' concept as a proxy to assess the number and location of rare species within a study area (Sanderson, 1996a, 1996b; Connor et al., 2002). The application of this concept is shown in Table 2. This approach has been adopted for the UK's Review of Marine Nature Conservation (DEFRA, 2004; Golding et al., 2004; Vincent et al., 2004; Lieberknecht et al. 2004a) and the UK Biodiversity Action Plan for marine species and habitats (UK BAP, 2005), both in combination with other criteria.

**Table 2: Approaches to apply the rarity criterion**

| | | |
|---|---|---|
| Rare | **Regionally rare** (sessile or of restricted mobility) **species** = | Connor *et al.* (2002) (only applicable |

| | | |
|---|---|---|
| species | species occurring in less than 2 % of the 50 x 50 km UTM grid squares of the following bathymetric zones in the region (f.i. North East Atlantic): littoral / sublittoral / bathyal, abyssal | to sessile species, no guidelines available for mobile species); Connor et al. (2004); Lieberknecht et al. (2004a, 2004b) |
| | **Nationally rare species** = species occurring in less than 0.5 % of the 10 km x 10 km squares within the study area | Sanderson (1996a,1996b); Connor et al. (2004); Lieberknecht et al. (2004a, 2004b) |
| | **Nationally scarce species** = species occurring in less than 3.5 % of the 10 km x 10 km squares within the study area | |
| | **Nationally rare species** = species found in fewer than x km squares in territorial waters | Hiscock *et al.* (2003); Department for Environment, food and Rural Affairs (2002) |
| Rare habitats | **Regionally rare habitat** = habitat type occurring in less than 2 % of the 50 x 50 km UTM grid squares of the following bathymetric zones in the region (f.i. North East Atlantic): littoral / sublittoral / bathyal, abyssal | Connor *et al.* (2002) |
| | **Nationally rare habitat** = habitat type restricted to a limited number of locations in territorial waters | Department for Environment, food and Rural Affairs (2002) |

A species described by the method of Sanderson (1996a, 1996b) as nationally rare or scarce, is not necessarily regionally or globally rare or scarce; it could simply be reported at the edge of its range or indicate subtle adversity such as stress caused by human activities in the study area. However, it could also be important to give a high value to subzones containing species at the margins of their range, because these sites could host important genetic stocks of a species. Also, populations of sessile southern or northern species have a poor capacity for recovery and recruit slowly at the northern, respectively southern, margins of their distribution and are therefore particularly vulnerable to even the most minor, infrequent impacts (Sanderson, 1996a, 1996b). Nationally rare or scarce species may also be restricted to specific habitat types that themselves may be rare in the study area and need to be given a high value (e.g. the rocky island habitats of Helgoland in the sedimentary southern North Sea).

A disadvantage of rarity assessment as discussed in Table 2 is that it may overlook local densities. Locally abundant species (in one or several subzones of a study area) which are restricted in their range might be considered to conflict with assertions made about national rarity, should population-based methods of assessment ever be used (Sanderson, 1996a, 1996b).

Uniqueness and distinctiveness (Roff and Evans, 2002) are also considered under this criterion and to assess the number and location of unique or distinct features/genetic stocks/species/communities within the study area, information on their occurrence is needed.

### 2. Aggregation

The ‘aggregation’ and ‘fitness consequences’ criteria will mainly identify subzones that have high ecological importance for the wider environment. Evaluation of these criteria therefore lies at the heart of an ecosystem approach to management, assigns value to subzones that “drive” ecological processes, and is one way to achieve preservation of the larger marine ecosystem (Brody, 1998). Ecosystem management forces us to adopt a holistic view of the components as parts of the system, rather than the reductionist view of single-species management, which ignores the fact that species exist only as part of the ecosystem (Simberloff, 1998). This is in agreement with the present concept of including as many components of biodiversity (both structural components and processes) in the criteria assessment as possible.

If data on the population size of a species are available at the scale of the study area, it is possible to determine whether a high percentage of a species’ population is located within a cluster of subzones of the study area. If these data are lacking and qualitative information exists on certain areas where species aggregate (wintering, resting, feeding, spawning, breeding, nursery, rearing area or migration routes), this information should be used as an alternative or addition to broad-scale quantitative abundance data. When the location of these areas is not documented, their existence and location may be predicted by examination of physical processes (incl. modelling) or remote sensing data, for example as indicated by Roff and Evans (2002) in their survey of distinctive marine areas. Alternatively, traditional ecological knowledge may assist in the definition of aggregation areas. It needs to be emphasized that any data, modelled or otherwise, needs to be assessed for its reliability and degree of confidence.

The inclusion of aggregation as a criterion for biological valuation introduces a certain degree of connectivity into the valuation concept, because this criterion is used to determine the aggregation value of subzones relatively to the subzones adjacent to them, allowing clustering those subzones with equal value.

The aggregation criterion is especially important for highly mobile species like birds, mammals or fish. For the preservation of such wide ranging species, information on their full distribution is less useful than localisation of areas which are critical for foraging, nursing, haul-out, breeding or spawning and these areas should be included when a biological valuation is done (Connor et al., 2002; Roff and Evans, 2002; Beck et al., 2003). When the study area under consideration is relatively small, the foraging areas of such highly mobile species could cover the whole study area, but it is still important to include them in the biological valuation as this can be an important signal to management as well.

Due to the continuous nature of the marine environment, it is difficult to identify the boundaries of such aggregation areas, especially for widely dispersed, highly mobile species (Johnston et al., 2002; Airamé et al., 2003). This can be seen in the difficulties encountered by many countries to implement the EC Bird Directive (1979) and Ramsar Convention (1971), which both select important bird areas based on high densities of bird species (Johnston et al., 2002).

### 3. Fitness consequences

This criterion distinguishes subzones where natural activities take place which contribute significantly to the survival or reproduction of a species or population (DFO, 2004). These are not necessarily areas where species or individuals aggregate. When genetic data are available for the study area, which is rarely the case, these can be used to locate subzones where a high diversity of genetic stocks of a species occurs. The occurrence of genetically variable individuals could significantly improve the survival of a species in the study area, because it enables the selective adaptation of the species to changing environmental conditions.

It is also possible to determine the location of subzones with fitness consequences for a species. These could be subzones where individuals stop for a certain amount of time to feed or rest, which will lead to a higher reproduction (e.g. bigger/more young). Also, the presence of structural habitat features or keystone species may enhance the survival or reproduction of species by providing refuge from predators or key resources.

### 4. Naturalness

The criterion ‘naturalness’ is indirectly included in site selection according to the EC Habitats Directive (1992), as several criteria need to be applied to ‘natural habitats’, which are defined as ‘(land or) water zones with special geographic, abiotic and biotic characteristics which can be either totally natural or semi-natural (as described in Annex I of the Directive)’. The problem with assessing this criterion is the fact that it is often unknown what the natural state of an area should be. Many assumptions may be made, but more studies are needed to help define what ‘natural’ really is (Bergman et al., 1991; Hiscock et al., 2003). There are also almost no completely natural areas left anymore (Ray, 1984) and it is difficult to assess the degree of naturalness in areas at great depth or in areas of bad accessibility (Breeze, 2004). So, in order to assess the naturalness of a subzone, there is a need for comparison to appropriate pristine areas or reference sites. If such areas do not exist, an alternative way to assess naturalness is to use information on native/introduced or cultured species in the study area, which can be seen as proxies for the degree of naturalness.

Another approach to assess the naturalness of a subzone is to look at the health or composition of the inhabiting communities/species. For instance, healthy, natural benthic communities are in many cases characterized by a high biomass (dominated by long-lived species) and high species richness (Dauer, 1993). Deviations from this pattern, resulting in a reduced macrobenthic biomass and species richness dominated by opportunistic species, could be assigned to a certain level of stress and could be used to index the naturalness of a subzone. Such health indices however still require some reference to a baseline level of naturalness.

Lacking even this information, one could use data on the location and intensity of human activities. The environmental and ecological state of subzones which are characterized by the absence of human disturbance can be used as a rough index of the degree of naturalness. Naturalness should not only consider the degree of disturbance to attributes of species, but also to functional processes of the marine ecosystem.

### 5. Proportional importance

Proportional importance measures the proportion of the national, regional and/or global resource of a species or feature which occurs within a subzone of the study area. While the ‘aggregation’ criterion investigates whether a high percentage of the species population at the scale of the study area is clustered within certain subzones of that area, the ‘proportional importance’ criterion investigates whether a high percentage of the species’ population on a national (provided that the national scale is greater than the scale of the study area), regional and/or global scale can be found in the study area, regardless if this proportion is clustered within adjacent subzones.

To assess this criterion, data on the extent of marine features or population data of individual species are needed. When population data are lacking, it may be possible to use available abundance data for species within the study area, and determine the national importance of subzones for these species. This criterion was first defined by Connor et al. (2002) and adapted by Lieberknecht et al. (2004a, 2004b), who also defined thresholds for the term ‘high proportion’. These thresholds are similar to those in the criteria guidance of OSPAR (2003). It was decided at the workshop on marine biological valuation that no thresholds would be set in the definition of the criterion, since they are very scale dependent and should therefore be set for every case study separately.

The biological valuation map represents the biological values of the different subzones considered, relative to each other, but incorporation of the proportional importance criterion aims at comparing certain features or properties with the wider environment of the study area, attaching extra value to subzones where a high proportion of the population of a species occurs. It could also be possible to include the genetic (e.g. restricted distribution of a certain genetic stock) or community (e.g. restricted distribution of a defined community type) level.

### 6. Biodiversity: a valid valuation criterion?

When valuing marine areas, it is important to capture as many attributes of biodiversity as possible, since biological structures and processes exist on different organizational levels (viz. genes, species, population, community and ecosystem) (Zacharias and Roff, 2000; 2001). According to Roberts et al. (2003a), valuable marine areas should be characterized by high biodiversity and properly functioning ecological processes which support that diversity. According to many authors the biodiversity of an area is simply a function of the species diversity, but we believe that a valuation framework that incorporates as many organizational levels of biodiversity as possible is far preferable.

Although the concept of biodiversity as a valuation criterion is highly attractive to managers, the practice of distilling biodiversity to a single index or a few dimensions is unjustified (Margules and Pressey, 2000; Purvis and Hector, 2000; Price, 2002), which is why biodiversity was not used as a criterion in our valuation concept. However, biodiversity is still integrated in the concept, but in a different way (see below). Yet, because of its frequent use (IUCN, 1994; HELCOM, 1992; Brody, 1998; UNEP, 2000; GTZ GmbH, 2002), we feel that a critical literature review and an argumentation for not including biodiversity as a valuation criterion in our concept are needed.

In most research studies only the species richness of a subzone is assessed (Humphries et al., 1995; Woodhouse et al., 2000; Price, 2002), but biodiversity manifests itself on many more levels of organisation (from the genetic to the ecosystem); simply counting the number of species in a subzone as measure for biodiversity can be misleading because subzones with a high species richness do not necessarily exhibit a high diversity on other levels (Attrill et al., 1996; Hockey and Branch, 1997; Vanderklift et al., 1998; Purvis and Hector, 2000; Price, 2002). Several authors have tried to find surrogate measures for biodiversity, in general in order to decrease the sampling effort or data requirements (Purvis and Hector, 2000). For example, Ray (1999) used species richness of birds as a surrogate for overall biodiversity, an approach which is based on the fact that birds have dispersed to and diversified in all regions of the world. Yet, analyses revealed that species richness hotspots of birds coincided poorly with those of other biota. Hotspots of species richness, endemism or rarity are often less discernible in continuous marine ecosystems than in terrestrial environments. Turpie et al. (2000) used the hotspot approach for species richness (and weighting all species equally) and did not achieve good representation for coastal fish species. Thus, the hotspot approach based on species richness alone is not a useful starting point for the selection of biological valuable marine areas. This was also noted by Breeze (2004), who found the traditional hotspot approach to be narrowly defined and species-focused, while the criteria used for identification of highly valuable marine areas should be much broader.

The use of focal species (indicators, umbrellas, flagship species), which has been developed mainly from a terrestrial viewpoint, is not straightforward to apply in the marine environment. Since connectivity is very different in the marine environment, the concept of a particular species indicating a certain size of intact habitat is not readily applicable (Ardron et al., 2002). Ward et al. (1999) also investigated the use of surrogates for overall biodiversity, and found that habitat types suited this function best. However, no surrogate was able to cover all species, from which it can be concluded that the hotspot paradigm, based on individual surrogates of biodiversity, is problematic to apply.

The concept of ‘benthic complexity’ was introduced by Ardron et al. (2002) as a proxy for benthic species diversity. The authors assume that the bathymetric (topological) complexity of an area is a measure of benthic habitat complexity, which in turn would represent benthic species diversity. However, the data needed to perform the spatial variance analyses needed to quantify ‘benthic complexity’ are usually lacking. Because detailed data on the diversity of species or communities are often scarce or nonexistent, Airamé et al. (2003) proposed to assess the habitat diversity as a proxy for overall biodiversity, because data on habitat distributions are generally available or can be constructed.

We feel that a more general framework for the assessment of biodiversity is needed (see e.g. Humphries et al*.,* 1995), and that this framework should use available information from a range of organizational levels (genes, species, communities, ecosystems), and that the relationships among these levels need to be examined. It is also emphasized that in addition to biodiversity 'structures', there is also a need to include biodiversity processes such as aspects of the functioning of ecosystems, which could even be more important than high species richness or diversity indices in certain low biodiversity sites like estuaries (Attril et al., 1996; Bengtsson, 1998). Bengtsson (1998) also stated that biodiversity is an abstract aggregated property of species in the context of communities or ecosystems, and that there is no mechanistic relationship between single measures of biodiversity and the functioning of the entire ecosystem. Ecosystem functioning can, however, be included indirectly in an assessment of biodiversity value, through the identification of functional species or groups and critical areas.

Zacharias and Roff (2000) visualised the various components of biodiversity in their 'marine ecological framework' (going from the species to the ecosystem level and including both biodiversity structures and processes). Each of these components can be linked to one or more of the selected valuation criteria, which makes it unnecessary to include biodiversity as a separate valuation criterion. By using this 'framework' it could therefore be possible to apply the valuation criteria while integrating various components of biodiversity.

## *E. POTENTIAL APPLICATION OF THE BIOLOGICAL VALUATION CONCEPT*

Once the concept of biological valuation is applied to a marine study area, the result of this process could be visualized on marine BVMs.

Marine BVMs can act as a kind of baseline describing the intrinsic biological and ecological value of subzones within a study area. They can be considered as warning systems for marine managers who are planning new threatening activities at sea, and can help to indicate conflicts between human uses and high biological value of a subzone during spatial planning.

It should be explicitly stated that these BVMs give no information on the potential impacts that any activity could have on a certain subzone, since criteria like vulnerability or resilience are deliberately not included in the valuation scheme, because the determination of the 'vulnerability' of a system is mainly a human value judgement (McLaughlin et al., 2002). These criteria should therefore be considered in a later phase of site-specific management (e.g. selection of protected areas) than the assessment of value of marine subzones (Gilman, 1997; 2002). The BVMs could be used as a framework to evaluate the effects of certain management decisions (implementation of MPAs or new quota for resource use), but only at a more general level when BVMs are revised after a period of time to see if value changes occur in subzones where these management actions were implemented. However, these value changes cannot directly be related to specific impact sources, but only give an integrated view on the effect of all impact sources in the subzone. The development of decision support tools for marine management could build on these BVMs by adding other criteria to the assessment concept. When developing a framework, suitable for the selection of Marine Protected Areas (MPAs), representativeness, integrity, and socio-economic and management criteria should also be taken into account (Rachor and Günther, 2001), especially when considering the need for management for sustainable use (Hockey and Branch, 1997). Managers may also want to know which areas should get the highest priority for. Therefore, the sites that attained the highest biological and ecological value could be screened, applying additional criteria like 'degree of threat', 'political/public concern' and 'feasibility of conservation measures'. Thus, although the ultimate selection of the priority areas may be a political decision (Agardy, 1999), selection can still have a solid scientific base through the use of BVMs. An overview of the possible steps beyond the development of a marine BVM is given in the lower part of Figure 1, which shows that, although these following steps should be founded in scientific biological valuation, they cannot be solely based on such criteria.

## *F. CONCLUSIONS*

- Marine biological valuation provides a comprehensive concept for assessing the intrinsic value of the subzones within a study area. Marine biological valuation is not a strategy for protecting all habitats and marine communities that have some ecological significance, but is a tool for calling attention to subzones that have particularly high ecological or biological significance and to facilitate provision of a greater-than-usual degree of risk aversion in spatial planning activities in these subzones.
- Based on a thorough review of existing criteria, a selection of criteria (first order criteria: aggregation, rarity and fitness consequences; modifying criteria: naturalness and proportional importance) was rationalized, aiming at a widely applicable valuation concept. We have also attempted to clarify the numerous criteria and definitions of value that are current in literature.
- As this biological valuation concept is based on the consensus reached by a group of experts on this matter, we realize that refinement of the methodology could be necessary once it has been evaluated on the basis of case study areas.

# III. Development of a marine biological valuation protocol

The following article is a direct end result of the BWZee project and gives an overview of the practical application of marine valuation criteria to a study area in order to develop a marine biological valuation map for that area. The article will be submitted for publication later this year.

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| Sofie Derous, Wouter Courtens, Pieter Deckers, Klaas Deneudt, Hans Hillewaert, Kris Hostens, Jan Mees, Ine Moulaert, Marijn Rabaut, John Roff, Eric Stienen, Vera Van Lancker, Els Verfaillie, Magda Vincx and Steven Degraer (in prep.). ***Biological valuation: Towards a scientifically acceptable and generally applicable protocol for the marine environment.*** To be submitted to Aquatic Conservation: Marine and Freshwater Environments. |

## *A. ABSTRACT*

Policy makers and marine managers request reliable and meaningful biological baseline maps to be able to make well-deliberated choices concerning sustainable use and conservation in the marine environment. Biological valuation maps compile and summarize all available biological and ecological information for a study area and allocate an integrated biological value to subzones. They can therefore be used as baseline maps for future spatial planning at sea. This paper gives guidelines on the practical application of the concept of marine biological valuation. All steps in the valuation protocol are described, starting from the selection of the valuation criteria over the determination of the appropriate assessment questions and practical algorithms to evaluate the criteria to the eventual scoring of all assessment questions. The marine biological valuation protocol is explained by using a hypothetical study area.

## *B. INTRODUCTION*

The continuously increasing socio-economical interest in marine resources and space urges the need for a decision making framework to objectively allocate the different user functions at sea and to manage them in a sustainable way (Tunesi and Diviacco, 1993; Vallega, 1995; Ray, 1999). Practitioners, stakeholders and policy makers therefore request clear and simple baseline maps in order to allow them making well-deliberated choices: e.g. usage maps may be used to detect conflicts in spatial distribution of human activities, whereas sedimentology maps allow to deliberately identifying suitable aggregate extraction zones. These maps are indispensable within the process of spatial planning. A protocol to develop baseline biological valuation maps (BVMs), differentiating between the intrinsic biological values of subzones within a study area, however does not exist yet. These BVMs would provide a useful “intelligence system” for managers and decision makers. Consequently, when such maps are lacking, one is often obliged to trust on the available best expert judgement.

Coastal planners and marine resource managers have utilized various tools for identifying ecologically valuable areas in the past, ranging from low-tech participatory planning as often used in community-based marine protected area (MPA) design (Agardy, 1997) over GIS-based multicriteria evaluation (Villa *et al.*, 2002) to high-tech decision-support tools such as MARXAN (Pressey *et al.*, 1997). The common element of all such approaches is the identification of criteria to discriminate between marine areas and guide the process of MPA selection; and whilst the vast majority of these efforts pertain to marine protected area design, there is no reason why such criteria cannot be equally helpful in coastal zone and ocean management more generally. However the disadvantages of these existing methods for assessing the value of marine areas have led to an increasing awareness that a rigorous and more objective procedure is needed. It is therefore necessary that the definition of the value of marine areas should be based on the assessment of areas against a set of objectively chosen ecological criteria, making best use of scientific monitoring and survey data (Mitchell, 1987; Hockey and Branch, 1997; Ray, 1999; Connor *et al.*, 2002; Hiscock *et al.*, 2003). Derous et al. (in press) selected five valuation criteria after reviewing the available grey and scientific literature on this topic. When applying these criteria to the biological data of a study area it should be possible to obtain an integrated view on the biological value of the subzones within the study area.

This paper aims at developing a biological valuation protocol around these valuation criteria which should be applicable in any marine area. Marine BVMs need to make best use of available data sets, compiling and summarizing relevant biological and ecological information for a study area, and allocating an overall biological value to different subzones.

## *C. A PROTOCOL FOR MARINE BIOLOGICAL VALUATION*

### 1. What is biological valuation?

Marine biological valuation encompasses the determination of the value of the marine environment from a nature conservation perspective. As such, marine biological valuation aims at providing an integrated view on nature's intrinsic value (i.e. without any reference to anthropogenic use), as opposed to socio-economic valuation aiming at the quantification of the goods and services.

The purpose of a marine biological valuation is the determination of subzones with a high, medium or low intrinsic biological value within a certain study area. Subzones would be scored on a relative scale, against a set of biological valuation criteria. In contrast to the hotspot approach, we do not want to highlight solely the most valuable subzones. The product of the valuation process, i.e. the intrinsic values of the subzones, can then be presented on marine biological valuation maps (BVM). The BVM can serve as a baseline showing the distribution of complex biological and ecological information. Such maps could be made on a national, regional or global scale.

Through a literature review the available valuation criteria were listed and these were screened during an international workshop in December 2004 (Derous *et al*., in press). The result of this screening process was a final selection of valuation criteria which should allow an objective and thorough biological valuation of a marine area: rarity, aggregation, fitness consequences (main criteria), naturalness and proportional importance (modifying criteria) (see table 1 in chapter II).

Around these criteria a concept for the biological valuation of marine waters was delineated with emphasis on its general applicability in different ecosystems and on its scientific acceptability (Derous et al., in press).

### 2. What can policy do with marine biological valuation maps?

Marine biological valuation maps can act as a kind of baseline describing the intrinsic biological and ecological value of subzones within a study area. They can be considered as warning systems for marine managers who are planning new threatening activities at sea, and can help to avoid sites which are labelled 'highly valuable' during spatial planning.

However, marine biological valuation maps give no information on the potential impacts of any activity on a certain subzone, since criteria like vulnerability or resilience are deliberately not included in the valuation scheme. The assessment of such criteria is mainly a human value judgement (McLaughlin *et al.*, 2002) and they should therefore not be considered when assessing the intrinsic biological value of a subzone. They can be included in a later phase of site-specific management (e.g. marine spatial planning). This is only one example of how the development of decision support tools for marine management could build on these valuation maps by adding other criteria to the assessment protocol. Other examples are shown in Figure 1 of chapter II and these relate to impact assessment studies, the selection of Marine Protected Areas (MPAs) or Priority Areas for Conservation (PACs). This figure shows that, although these following steps should be founded in scientific biological valuation, they cannot be solely based on such criteria. For instance, when selecting PACS, the sites that attained the highest biological and ecological value according to the biological valuation, could be screened, applying additional criteria like 'degree of threat', 'political/public concern' and 'feasibility of conservation measures'. Thus, although the ultimate selection of the PACs may be a political decision (Agardy, 1999), selection can still have a solid scientific base through the use of biological valuation maps.

### 3. The concept of 'biodiversity'

As many ecosystem components as possible should be included in the biological valuation of a study area. Also the concept of biodiversity should not be treated as a valuation criterion, but instead all other selected valuation criteria should be assessed on all levels of biodiversity (as far as biological data are available for doing this). Zacharias and Roff (2000) visualised the various components of biodiversity in their 'marine ecological framework' (going from the species to the ecosystem level and including both biodiversity structures and processes). Their framework was further developed, adding the genetic level of biodiversity and including more components of structure and process/function at the different levels and is presented in Annex B. In most of the world's marine environments, genetic diversity is poorly understood and has not been a significant factor influencing the assessment of valuable areas (Attrill *et al.*, 1996; Roberts *et al.*, 2003a, 2003b). The scheme presented in Annex B can now be used as a guiding tool that explicitly includes all biodiversity components in a marine valuation framework.

By asking a set of possible assessment questions, related to different structures and processes of biodiversity, coupled to the proposed valuation criteria, a comprehensive valuation assessment protocol has been established (see Annex B). This question-approach is similar to that used by Smith and Theberge (1986) to evaluate natural areas according to a set of criteria. Detailed questions about structures and processes of biodiversity can lead to a more objective valuation, because experts could otherwise score a criterion from their own individual perspectives and comparison among valuations would be difficult. When applying this framework to a given study area, experts should select the questions most appropriate for that area (regarding the data available, the presence of certain processes/structures, etc.) and determine the thresholds needed to score the questions. It seems impossible to set uniform thresholds which would be applicable to all marine ecosystems, so this needs to be done on a case by case basis. When all relevant questions are scored for the different subzones within a study area, all criteria (with respect to all organizational levels of biodiversity) are assessed. This will lead to subzones with different biological and ecological values (e.g. low, medium, high value) and the highly valued subzones can then be considered 'hotspots' that reflect the highest biological value within a study area, considering **all** possible aspects of biodiversity and habitat diversity. Thus, in our approach 'hotspots' are seen as subzones which have or are perceived to have 'more' intrinsic biological value because of their combinations or greater numbers of biodiversity attributes. This is similar to the hotspot theory of Ray (1999), but extended to the full spectrum of biodiversity attributes. In this way the hotspot approach, based on species richness or rarity, is now coupled to an extended set of other criteria, and the whole framework can be used to assess the intrinsic value of the different subzones within a study area.

The scheme in Annex B gives an overview of all possible aspects which could be considered when doing a marine biological valuation of a study area. It allows the selection of the most appropriate set of valuation assessment questions and biodiversity organizational levels, based on the geographical location, the ecosystem and the data availability of the study area. How these specific aspects should be practically assessed and scored will be shown in a next paper (where an example of the development of a marine biological valuation map will be shown), the scheme only gives the conceptual path which should lead to valuation of a marine study area.

## 4. Subdividing the study area

Before the assessment of the biological and ecological value of a study area can be carried out, a division of the area into subzones (also called ecounits: Zacharias and Howes, 1998) is needed. This division should preferably be ecologically and physically meaningful (Laffoley *et al.*, 2000a) and practical, allowing the comparison of biological value between defined subzones.

Different methods to classify a study area into subzones (i.e. zoning) have been proposed in literature. Marine biogeographical classifications can be done in several ways and at different scales (global, regional, provincial and local). Ideally, classification schemes that separate a study area into biogeographically similar subzones that can then be meaningfully compared should be used (Ray, 1984), but ecologically meaningful classifications on smaller scales (within one biogeographical region) could be suitable as well. Due to the lack of distinct biogeographical boundaries in the sea, there are still no generally accepted marine biogeographical classification schemes (Lourie and Vincent, 2004). On a more local scale, a detailed, hierarchical biotope classification scheme has been developed for the benthic environment in the UK, based on a combination of physical habitat data and detailed biological data (Connor *et al.*, 2004), but this classification scheme is only suitable for inshore areas with high data availability. Most marine classification schemes are more broadscale (regional/provincial), using characteristics of the local abiotic environment such as sediment characteristics, morphological features of the seabed, water circulation etc., to subdivide the marine environment (Tunesi and Diviacco, 1993; Rachor and Günther, 2001; Bax and Williams, 2001; Roff *et al*., 2003; Golding *et al*., 2004). Ideally, both bottom habitat features and pelagic features should be incorporated into a classification scheme, because biological valuation should be done for both layers within the ecosystem (Roff *et al*., 2003; Breeze, 2004). Such broadscale, physical habitat classification is based on features that are relatively easily mapped and managed, especially in data-poor situations typical of many marine environments (Bax and Williams, 2001). Since the distribution of marine biota, and especially of macrobenthos, mirrors well the distribution of these features, this kind of division will be biologically meaningful (Rachor and Günther, 2001; Golding *et al.,* 2004). However, small-scaled conservation actions will still need more detailed classification scheme, like the UK habitat classification scheme (Connor *et al*., 2004), to be effective. For the purpose of marine biological valuation a division of the study area in subzones according to a habitat classification seems most appropriate, because biogeographical classifications don't allow fine-scaled valuations and local biotope classifications demand more data to be available. If even such habitat classification is not possible due to data unavailability, the study area can be divided into subzones by simply placing a raster on the map of the subzone where each grid cell represents a different subzone. In this case care should be taken that the size of the grid cells is ecologically meaningful for the ecosystem component under consideration. For seabirds for instance it could be advisable to use 3x3 km grid cells, while smaller grid cells of 250x250 m could be more advisable for the relatively immobile benthos.

## 5. Collection of available biological and ecological data

Before the actual biological valuation of the subzones within a study area can be done, it is necessary to collect all available biological and ecological data of the study area in a database and to assign the data to the different subzones.

Despite extensive lists of ecological criteria on value present in literature (see Annex A), the majority of such criteria are not applied, due either to the lack of available data to assess them and/or to the urgent (usually political) need to select valuable areas (Rachor and Günther, 2001). Most efforts for the identification of valuable marine areas are initiated at the habitat level, with particular emphasis on structures (bottom topography, wave exposure, depth, substrate type, etc.), because these are the most easily observed features in marine environments and are usually well documented in large databases, which does not hold true for population or community structures (e.g. indicator species, species diversity, functional groups, etc.) (Zacharias and Roff, 2001).

In the present paper a flexible method is proposed, where it is possible to assess the valuation criteria according to the data availability. However, if despite this flexibility data are lacking for certain subzones these subzones will need to be indicated on the marine BVM.

## 6. Design of the valuation protocol

When all biological and ecological data of a study area are collected the valuation criteria can be applied to the different subzones of that study area using the protocol explained in Appendix 1 (see Annex B). The assessment questions in appendix 1 relate to the valuation criteria and to a specific organizational level of biodiversity. Based on the available biological data the relevant assessment questions can be selected. By developing specific assessment algorithms for each assessment question the question can be quantitatively assessed. Examples of such assessment algorithms are given for seabird, macrobenthos, epibenthos and hyperbenthos data in Table 3.

**Table 3: Examples of algorithms which can be used to apply the assessment questions to data of different ecosystem components. If there are no data available for a certain subzone within a study area, this subzone is labeled "NA" and is not incorporated when the algorithm is applied.**

| | Assessment question (criterion) | Algorithm |
|---|---|---|
| **Seabirds** | High counts of many species (A) | 1. Determine the species which are regularly occurring in your study area. Then select all species which occur in more than 1 % of your records (this is done to exclude rare species from the species list).<br>2. Interpolate density data of seabird species to the chosen subzones.<br>3. Create 5 density classes with values between 1 and 5 (with an equal amount of subzones in each class).<br>4. Assign values to data for all species and sum the values in every subzone.<br>5. Divide the resulting summed values again in 5 classes (with an equal amount of subzones in each class). |
| **Macrobenthos** | Habitats formed by keystone species (R, A, F, N) | 1. Select habitat structuring species from species list (e.g. *Lanice conchilega* is a tubeworm occurring on the BPNS, which is known to build small reefs on the seabed. These reefs give structure to the habitat, which attracts other species).<br>2. Create 5 density classes for this species with values between 1 and 5 (using the density range).<br>3. If there are several habitat structuring species present in the study area, then create different density classes for each species separately and average the values afterwards. |
| | Distinctive/ unique | 1. Determine the different macrobenthic communities in |

| | | | |
|---|---|---|---|
| | communities (R) | | the study area and calculate the average species richness (#sp/m²) and density (ind/m²) for each community (= $SPR(comm_1)_{avg}$, $DENS(comm_1)_{avg}$, $SPR(comm_2)_{avg}$,…). |
| | | 2. | Determine the maximum species richness and density occurring in the study area (= $SPR_{max}$ and $DENS_{max}$) |
| | | 3. | Calculate the ratios $SPR(comm_x)_{avg}/SPR_{max}$ and $DENS(comm_x)_{avg}/DENS_{max}$ for every community. |
| | | 4. | Translate these ratios to values between 1 and 5 and sum the ratio for species richness and the one for density for each community. Divide these values again by 2 to get values between 1 and 5. |
| | | 5. | Assign these values to each subzone according to the community that was characterized in this zone. If a mixture of communities is occurring in one subzone, assign the value corresponding to the community with the highest frequency of occurrence in that subzone. |
| **Epibenthos** | High species richness (A, R, F) | 1. | Determine the average epibenthic species richness for each subzone. |
| | | 2. | Create 5 species richness classes with values ranging from 1 to 5 (with an equal amount of subzones in each class). |
| **Hyperbenthos** | Ecological significant species (R, F) | 1. | Select ecological significant species from species list. Such species could be species which constitute important food sources of certain seabirds (e.g. *Mesopodopsis slabberi* in the coastal zone of BPNS) or species which are important for recruitment of fish stocks (e.g. fish larvae in BPNS). |
| | | 2. | Create 5 density classes for this species with values ranging from 1 to 5 (with an equal amount of subzones in each class). |
| | | 3. | If there are several ecological significant species present in the study area, then create different density classes for each species separately and average the values afterwards. |
| | Highly productive subzones (A, F) | 1. | Determine the average hyperbenthic biomass for each subzone. |
| | | 2. | Create 5 biomass classes with values ranging from 1 to 5 (with an equal amount of subzones in each class). |

## 7. Scoring

When evaluating subzones against the chosen criteria, a scoring system needs to be applied. Due to the inherent complexity of marine ecosystems and the lack of subzone-specific data, quantitative scoring is often impossible and the subzones are qualitatively scored against the criteria. However, this can make the valuation procedure very subjective and difficult to apply in a transparant and defensible manner. The only alternative is to work with a semi-quantitative scoring system (i.e. categories of high, medium, low), a method that could even be used when data are incomplete and expert judgement is used to complete the information (Croom and Crosby, 1998 (cited in Brody, 1998); Levings and Jamieson, 1999; WWF, 2000; Breeze, 2004). Such semi-quantitative scoring system was used in the development of the terrestrial biological valuation maps of Belgium (De Blust *et al*., 1985; 1994). Other authors have used mathematical software tools, like SITES and MARXAN to score the criteria for a certain study area (Freitag *et al.*, 1997; Pressey *et al.*, 1996, 1997; Ardron *et al.*, 2002; Gladstone, 2002; McDonnell *et al.*, 2002; Stewart and Possingham, 2002; Beger *et al.*, 2003; Roberts *et al.*, 2003b; Breeze, 2004, Lieberknecht *et al*., 2004b). Because these methods require quantitative biological data for all evaluated subzones, they will not be applicable in every marine environment.

Although the inclusion of expert judgement in a semi-quantitative scoring system makes the valuation process less objective, it is also the scoring system which is still frequently used in the marine environment, where biological data are often lacking. Hockey and Branch (1997) suggested that the scoring system should be kept as flexible as possible so that it can be modified to be more sensitive or emphasize particular objectives if there are substantiated biological reasons for doing so. However, it is felt that such flexible scoring system would even more diminish the objectivity of the valuation process.

It is suggested that an equal weight should be attached to all 1$^{st}$ order criteria, and that the modifying criteria can then be used to upgrade the value of a subzone when their score is high. To assess the score for each criterion, the relevant questions from Annex B must first be chosen and answered for each subzone of the study area. Then the overall intrinsic value of each subzone can be determined by evaluating the individual scores for each of the criteria. These individual scores can be combined in different ways (addition, multiplication, averaging, etc.). Another scoring approach is to label a subzone with 'high' intrinsic value if it scores high on only one criterion (De Blust *et al.,* 1985; 1994). For this biological valuation protocol we chose to add the scores for all 1$^{st}$ order criteria together and to adapt the resulting value according to the score for the modifying criteria, when needed (see Table 4 for an example with hypothetical scores and subzones; the scores per assessment question range from 1 to 5). The criteria scores are also separated for different ecosystem components (so there are different scores for each criterion and subzone according to which data – seabird data, macrobenthos data, … - are evaluated). The biological valuation process proposed here is now being tested on the BPNS and the results of the scoring process will be evaluated to see if addition of the individual scores of the 1$^{st}$ order criteria is suitable for this purpose or not. A same exercise will be done for other European sites in the near future (in the framework of the European MARBEF project).

**Table 4: Example of the proposed scoring system for a hypothetical study area with 6 subzones. The individual scores for every criterion are also hypothetical and only used to illustrate the scoring process. After each assessment question (selected from appendix 1 – Annex B - according to the available biological data) the relevant criterion can be found (R=rarity, A=aggregation, F=fitness consequences, N=naturalness, P=proportional importance). When no biological data are available for a certain subzone this is indicated by NA. The values are given by the following codes (VL=very low, L=low, M=medium, H=high, VH=very high).**

| | | Subzone | | | | | |
|---|---|---|---|---|---|---|---|
| | **Assessment question (criterion)** | **1** | **2** | **3** | **4** | **5** | **6** |
| **Seabirds** | high counts of many species (A) | 2 | 5 | NA | 1 | 4 | 1 |
| | high abundance certain species (A) | 5 | 4 | NA | 4 | 3 | 2 |
| | high % species population (A, P) | 1 | 4 | NA | 1 | 3 | 1 |
| | high species richness (A, R, F) | 3 | 4 | NA | 2 | 3 | 2 |
| | **Number of 1$^{st}$-order questions answered (#Q)** | 4 | 4 | 0 | 4 | 4 | 4 |
| | **Total score 1$^{st}$-order criteria** | 11 | 17 | NA | 8 | 13 | 6 |
| | **Intermediate value** *(see (*1))* | M | VH | NA | L | M | VL |
| | **Average score of modifying criteria (here: P) = 4-5?** | No | Yes | NA | No | No | No |
| | **Upgrade of intermediate value?** | M | VH | NA | L | M | VL |
| **Macrobenthos** | high counts of many species (A) | 3 | NA | 2 | NA | 4 | 2 |
| | high abundance certain species (A) | 2 | NA | 4 | NA | 5 | 3 |
| | presence of rare species (R) | 1 | NA | 5 | NA | 3 | 2 |
| | abundance of rare species (R) | 2 | NA | 2 | NA | 2 | 2 |
| | habitat formed by keystone species (R, A, F, N) | 1 | NA | 5 | NA | 3 | 2 |
| | distinctive/unique communities (R) | 2 | 2 | 2 | 1 | 5 | 1 |
| | ecologically significant species (R, F) | 2 | NA | 3 | NA | 3 | 2 |
| | high species richness (R, A, F) | 3 | NA | 4 | NA | 5 | 1 |
| | highly productive sites (F) | 2 | NA | NA | NA | 2 | NA |
| | **Number of 1$^{st}$-order questions answered** | 9 | 1 | 8 | 1 | 9 | 8 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **(#Q)** | | | | | | |
| **Total score 1st-order criteria** | 18 | 2 | 27 | 1 | 32 | 15 |
| **Intermediate value** *(see (*1))* | L | L | M | VL | H | L |
| **Average score of modifying criteria (here: N) = 4 - 5?** | No | No | Yes | No | No | No |
| **Upgrade of intermediate value?** | L | L | H | VL | H | L |

| *(*1) Classification intermediate value* | **Range of total score first-order criteria** | | **Value (numerical)** |
|---|---|---|---|
| | **Min** | **Max** | |
| | #Q | 9/5 * #Q | VL (1) |
| | 9/5 * #Q | 13/5 * #Q | L (2) |
| | 13/5 * #Q | 17/5 * #Q | M (3) |
| | 17/5 * #Q | 21/5 * #Q | H (4) |
| | 21/5 * #Q | 5 * #Q | VH (5) |

| | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| **Intermediate value seabirds** | M | VH | NA | L | M | VL |
| **Intermediate value macrobenthos** | L | L | H | VL | H | L |
| **Average total numerical value** | 2.5 | 3.5 | 4 | 1.5 | 3.5 | 1.5 |
| **Total value (average)** *(see (*2))* | **L** | **H** | **H** | **VL** | **H** | **VL** |
| **Reliability of seabird data (based on sampling intensity)** | H (3) | L (1) | NA (0) | H (3) | H (3) | M (2) |
| **Reliability of macrobenthos data (based on sampling intensity)** | L (1) | L (1) | M (2) | L (1) | H (3) | M (2) |
| **Total reliability (= average of separate reliability scores)** | M (2) | L (1) | M (2) | M (2) | H (3) | M (2) |

| *(*2) Determination of total value (using the numerical equivalents of the intermediate values)* | **Range of average total numerical value** | | **Total value** |
|---|---|---|---|
| | **Min** | **Max** | |
| | 1 | 1.8 | VL |
| | 1.8 | 2.6 | L |
| | 2.6 | 3.4 | M |
| | 3.4 | 4.2 | H |
| | 4.2 | 5 | VH |

## 8. Reliability and revision

Biological valuation maps (BVMs) should not be seen as unchangeable, rigid, and fully explanatory maps depicting the relative intrinsic value of subzones. A detailed database, covering all data and information used for the value assessment, should be attached to the maps, and this should be consulted whenever the maps are used as an advice and warning system in management decisions.

The reliability of the assessed intrinsic value should be noted, for instance by attaching a label displaying the amount and quality of the data used to assess the criteria in a certain subzone (e.g. Breeze, 2004) (see Table 4 and Figure 1 above). If certain criteria could not be assessed due to a lack of available data, this should also be noted, because this could seriously lower the reliability of the resulting biological valuation. Such quality labels should also be consulted by anyone using the biological valuation maps. Attaching such 'reliability labels' also helps to identify knowledge gaps, which could direct scientific research in the future.

It should be noted that a BVM provides the relative values of different subzones given the available data at that time. This requires that BVMs need to be revised on a regular basis to meet the dynamics of the marine ecosystem and whenever new relevant data become available (e.g. on other ecosystem components).

### 9. Presentation of biological values of subzones

The results of the biological valuation of a study area can then be presented on a map, where each subzone within the area is assigned a colour corresponding with its value. Figure 2 gives an example of the valuation protocol applied to a hypothetical study area. The values given are purely indicative as they are based on fictive data (see Table 4 above). Reliability can also be indicated by using different intensities of a colour or other markings.

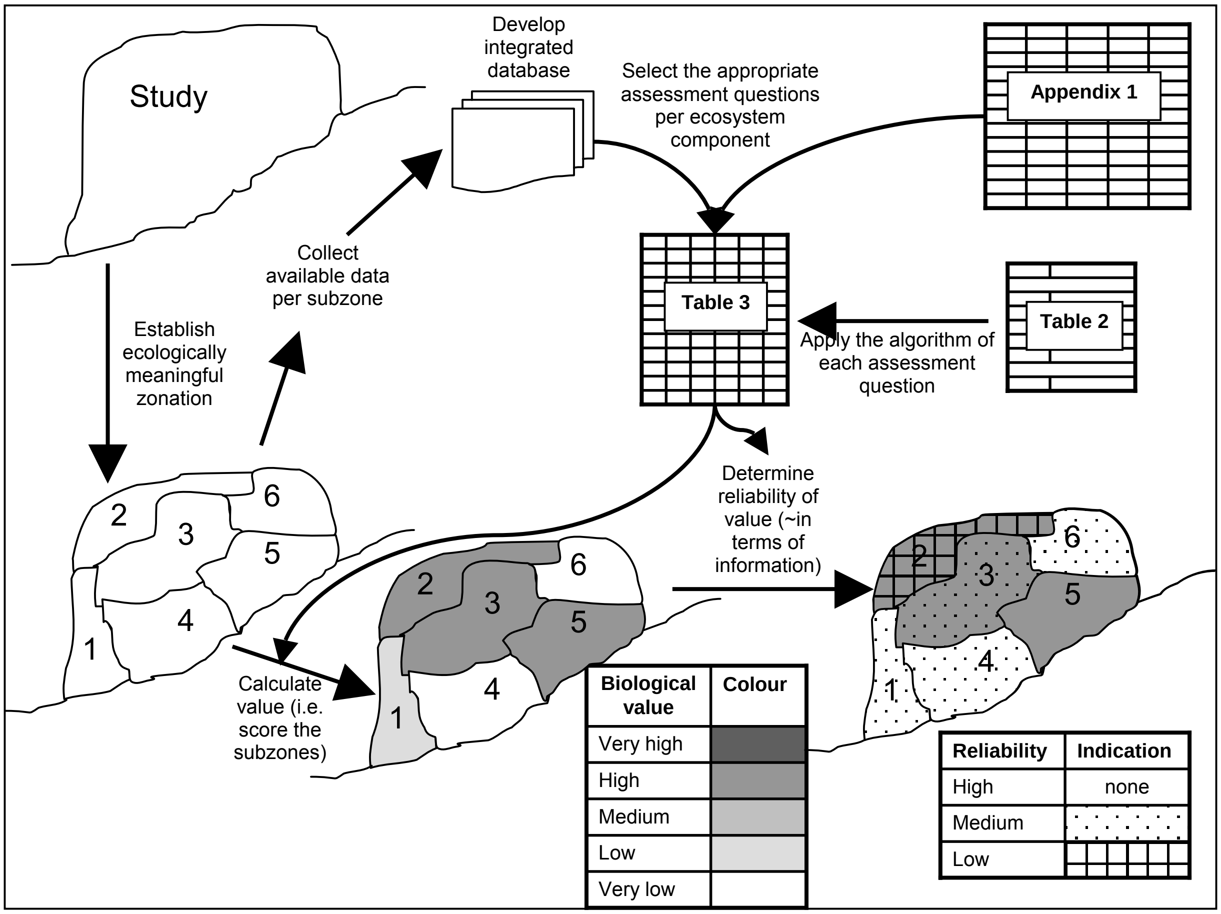


**Figure 2: Example of the application of the marine biological valuation protocol to a hypothetical study area with 6 subzones. The values and reliability labels are also hypothetical and only used to illustrate the protocol.**

## *D. CONCLUSIONS*

This paper presents guidelines for the practical application of the marine biological valuation concept to a study area. Marine biological valuation aims at evaluating the intrinsic value of each subzone within that study area relatively to each other. After dividing the study area into subzones and collecting the available biological data, the valuation criteria can be scored by answering specific assessment questions, relevant to the criteria and with respect to the different organizational levels of biodiversity. This protocol allows assessing the biological value of subzones based on the proposed criteria in study areas with various levels of data available.

By formulating clear algorithms for each assessment question it is possible to objectively evaluate each subzone of subzone according to these assessment questions.

Different scoring methods are proposed in this paper and an example is given based on fictive values of a hypothetical study area.

# IV. Spatial extrapolation of macrobenthic data

The following article is a direct end result of the BWZee project and gives an overview of the use of habitat suitability as a tool to develop full-coverage maps for macrobenthos. The adapted and extended version of this article will be submitted for publication to "ICES Journal of Marine Science" in March.

Steven Degraer , Els Verfaillie, Wouter Willems, Els Adriaens, Vera Van Lancker, and Magda Vincx (submitted). ***Habitat suitability modelling as a mapping tool for macrobenthic communities: an example from the Belgian part of the North Sea.*** Submitted to ICES Journal of Marine Science.

## *A. INTRODUCTION*

Due to its ecological importance and obvious presence within the marine ecosystem, the macrobenthos is one of the most intensively investigated marine ecosystem components. Data on the spatial distribution of macrobenthic species and species assemblages are available for many areas worldwide. Being ecologically important and well-known, the spatial distribution patterns of the macrobenthos are often used to ecologically adjust marine management.

Though in many cases the macrobenthic spatial distribution is relatively well-known, this information is merely restricted to the level of sampling stations: although being increasingly demanded, full-coverage spatial distribution maps are generally lacking (ICES, 2005). In general, two strategies could be followed to attain full-coverage distribution maps: (1) spatial extrapolation based on sampling point information (i.e. spatial extrapolation) (e.g. Dutch part of the North Sea: Holtmann et al., 1996) or (2) combining (full-coverage) data on the abiotic benthic habitat and quantitative knowledge of the macrobenthic habitat suitability (i.e. predictive modelling). Though being attractive, spatial extrapolation is perilous since often community structure might change within very short distances. Degraer et al. (2002) demonstrated that – for instance in the geomorphologically highly diverse Belgian coastal zone – even a dense grid of sampling stations (120 sampling stations in 5x5 km area) did not allow to spatially extrapolate the macrobenthic community distribution patterns. Spatial extrapolation further has the disadvantage that a rather static map is produced: whenever new data become available, the whole extrapolation exercise has to be repeated. Predictive modelling of habitat suitability, on the other hand, allows to objectively produce distribution maps at a level of detail determined by the availability of environmental data. In areas were detailed abiotic habitat information is present, small-scale patchiness within the macrobenthos will as such be detected. Once the predictive model is set, this strategy further allows to easily update the spatial distribution whenever more detailed abiotic habitat data become available. If full-coverage maps of the environmental variables (f.i. physical habitat) are available, it would even be possible to create a full-coverage map of the macrobenthos' spatial distribution.

This study aims at demonstrating the usefulness of habitat suitability modelling as a mapping tool with high relevance for marine management. This exercise will be performed using data from the well-investigated BPNS and dealt with in two steps: (1) the construction of a habitat suitability model for the macrobenthic communities at the BPNS (i.e. modelling) and (2) a maximisation of the knowledge on the macrobenthic spatial distribution at the BPNS, applying the habitat suitability model to full-coverage environmental maps (i.e. mapping).

## *B. MATERIALS AND METHODS*

### 1. The Belgian part of the North Sea: current knowledge

The Belgian part of the North Sea (BPNS) has a surface area of only 3600 km², but comprises a wide variety of soft sediment habitats (Verfaillie et al., 2006). Due to the presence of several series of sandbanks, the area is characterized by a highly variable and complex topography. Consequently, sediment types are highly variable throughout the area. Since the spatial distribution of the macrobenthos is largely depending on the physical environment, a high diversity of macrobenthic life can be expected (Degraer et al., 1999).

Being small, detailed knowledge on the macrobenthos' spatial distribution at the BPNS became available through several Flemish and Belgian research projects. Based on a combination of these datasets, Degraer et al. (2003) and Van Hoey et al. (2004) summarized the soft sediment macrobenthic community structure. They discerned between four subtidal communities: (1) the *Macoma balthica* community, (2) the *Abra alba – Mysella bidentata* community (or *A. alba* community; Van Hoey et al., 2005), (3) the *Nephtys cirrosa* community and (4) the *Ophelia limacina – Glycera lapidum* community (further called: *O. limacina* community). Next to these communities, several transitional species assemblages, connecting the three communities, were defined.

Each community was restricted to a specific habitat. Sediment grain size distribution (i.e. median grain size and sediment mud content) was identified to be the major structuring physical variable.

Because of its high macrobenthic diversity, in combination with a detailed knowledge of the macrobenthic community structure, the BPNS represents an ideal case study area for the development of a predictive model to attain a (full-coverage) spatial distribution map of the macrobenthos.

### 2. Research strategy

Two major steps can be distinguished within the research strategy: (1) habitat suitability modelling and (2) full-coverage mapping of the macrobenthic habitat suitability (Figure 3). The first step comprises a thorough confrontation of the biological point data with the accompanying physical data, aiming at creating a solid mathematical habitat suitability model. In the second step the habitat suitability model was applied to the full-coverage maps of the ecologically most relevant physical data in order to attain a full-coverage habitat suitability map.

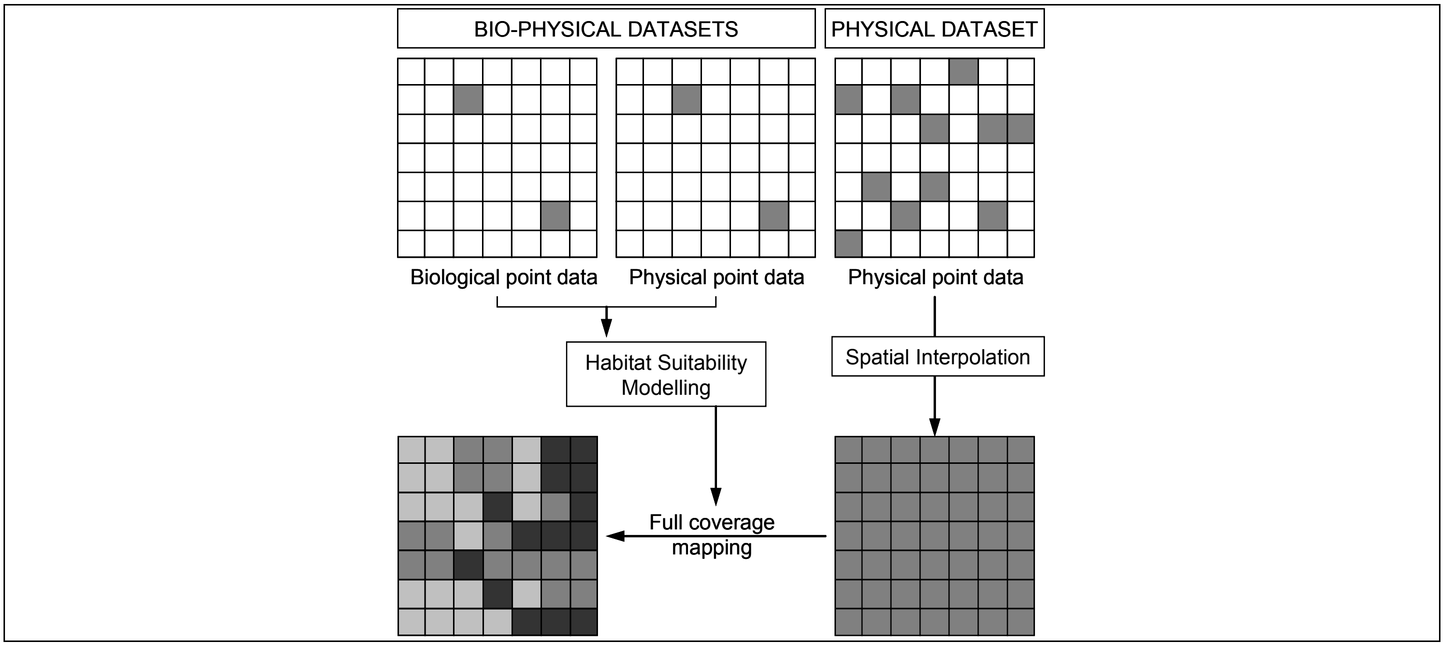


**Figure 3: Schematic presentation of the research strategy, starting from bio-physical and physcial point data to a full-coverage macrobenthic habitat suitability map.**

## 3. Data availability

- BIOLOGICAL DATA

Within the framework of several projects 1197 macrobenthos samples were collected at the BPNS between 1994 and 2004. The samples were all collected with a Van Veen grab (sampling surface area: 0.1 m²) and sieved over a 1 mm mesh-sized sieve. All organisms were identified to species level, whenever possible, and species-specific densities (ind/m²) were determined.

Before analysis, a thorough data quality control was performed. Non-representatively sampled species were excluded from the dataset. A first set of non-representatively sampled species consisted of non-macrobenthic species, such as hyperbenthic mysids, fish and pelagic larvae), which cannot representatively be sampled with a Van Veen grab. A second set consisted of rare species, here defined as any species with a frequency of occurrence of less than 2 % and encountered with a maximum of three individuals per sample. Because datasets, derived from different research projects, were combined, the dataset was checked for inconsistent species identifications. In case of inconsistent species identifications (e.g. *Bathyporeia* spp., *Capitella* spp. and *Ensis* spp.), the species were lumped to the taxonomically highest common denominator. To avoid temporal autocorrelation, temporal series were excluded from the analysis. After data quality control the final dataset comprised 773 samples and 123 species.

- ENVIRONMENTAL DATA

Model input data

To maximise the applicability of the habitat suitability model only frequently measured and/or widely available environmental variables were offered in the modelling exercise. A first set of environmental data were composed of variables measured *in situ*, i.e. median grain size, sediment mud content and water depth. Other environmental variables were taken from models: water depth (in case depth was not measured *in situ*) and slope were estimated on the basis of detailed bathymetric maps (unpubl. data E. Verfaillie, UGent-RCMG). Finally, distance to the coast, calculated from the geographic position of the sampling points, was included in the list of potentially explanatory variables.

Full-coverage environmental maps

The bathymetric map of the BPNS is based on single beam echosounder data from the IVA Maritime Services and Coast, Flemish Hydrography and completed with data from the Hydrographic Office of the Netherlands and the United Kingdom. This dataset was interpolated using a simple inverse distance algorithm to a digital terrain model with a resolution of 80 m. The slope map is the first derivative of the bathymetric map. It is expressed in degrees and has a resolution of 80 m. Full-coverage median grain size and mud content maps with a resolution of 250 m were derived from the 'sedisurf@' database (UGent-RCMG), containing more than 6000 data points, spread throughout the BPNS and collected since 1976. At first, the database was cleaned using a 'zonation approach' and extreme or unrealistic data points were removed. To create full-coverage median grain size maps, Kriging with an external drift was used, taking into account bathymetry as a secondary variable to assist in the interpolation (for more detailed information: Verfaillie et al., 2006). The map of the mud content was created, using Ordinary Kriging with directional variograms for the anisotropy of the data (for more detailed information: Van Lancker *et al.*, in prep.).

## 4. Habitat suitability modeling

- MODELLING STRATEGY

Since the relevance for marine management is a major aim of this paper, the outcome of the modelling and mapping exercise should be easy to communicate to politicians, policy-makers and managers (Olsson & Andersson, 2007). Hence, although we acknowledge macrobenthos to be structured along gradients, an abstraction of this complexity was set: instead of modelling the detailed macrobenthic gradients, we deliberately focused our model on the prediction of the chance of occurrence of each of the four macrobenthic communities, given a set of environmental factors. As such, the macrobenthos was mapped at the community level, a level of detail allowing an easy communication and interpretation of the final outcome within a management perspective. To assure the incorporation into the model of only macrobenthic communities (i.e. distinct sample groups from the multivariate analyses), transitional species assemblages were excluded from the predictive modelling exercise. Restricting datasets to discrete groups is regularly done in modelling exercises.

- BIOLOGICAL DATA EXPLORATION: COMMUNITY ANALYSIS

The community structure was investigated by several multivariate techniques: Group-averaged cluster analysis based on Bray-Curtis similarity (Clifford and Stephenson, 1975), Detrended Correspondence Analyses (DCA) (Hill and Gauch, 1980) and Two-Way Indicator Species Analysis (TWINSPAN) (Hill, 1979; Gauch and Whittaker, 1981), based on the final dataset with 773 samples and 123 taxa. For cluster analysis and DCA the data were fourth-root transformed prior to analysis. TWINSPAN was run using both the species density data as well as the presence/absence data.

The outcome of each multivariate analysis was compared to extract consistent groups of samples. Samples that were placed in different sample groups by the different multivariate analyses were considered as inconsistently grouped and were excluded from further analysis. This strategy assures that atypical observations (i.e. inconsistently grouped samples) do not bias any further analysis.

To designate the multivariately defined sample groups to the macrobenthic communities, as defined by Van Hoey et al. (2004) (i.e. *A. alba*, *N. cirrosa* and *O. limacina* communities), the relative distribution (%) of the samples over the macrobenthic communities was calculated per sample group. Because samples, belonging to the *M. balthica* community, were not present in the database, used by Van Hoey et al. (2004), sample group designation to the latter community was based on Degraer et al. (2003). Each sample group was designated to the community or transitional species assemblage (TSA) with the highest relative distribution value. For a detailed description (biology and environment) of all communities and TSAs one is referred to Degraer et al. (2003) (*M. balthica* community) and Van Hoey et al. (2004) (*A. alba*, *N. cirrosa* and *O. limacina* – *G. lapidum* communities).

- DISCRIMINANT FUNCTION ANALYSIS

Discriminant function analysis (DFA) was used (1) for detecting the abiotic habitat variables allowing to discriminate between different macrobenthic communities and (2) for computation of the habitat suitability model, using the full-coverage environmental maps.

The standardized beta coefficients for each abiotic habitat variable within the discriminant functions were used to detect structuring abiotic habitat variables: the larger the standardized coefficient, the greater is the contribution of the respective variable to the discrimination between groups.

The habitat suitability model comprised the DFA classification probabilities (i.e. habitat suitability), based on the grid cell's Mahalanobis distance[1] from the different community centroids. In general, the further away a grid cell is from a community centroid, the less likely it is that the habitat of the grid cell is suitable for that community.

- HABITAT SUITABILITY MAPPING

The habitat suitability model was applied to the full-coverage maps of the ojectively selected explanatory environmental variables (see DFA). The classification probabilities – or the habitat suitability – for each community was computed per grid cell. As such, a habitat suitability map (0 to ≈ 100 %) for each macrobenthic community was derived. However, not all grid cells allowed a reliable habitat suitability estimate: grid cells with a Mahalanobis distance of three times the standard deviation from any macrobenthic community centroid (as calculated from the Mahalanobis distances from the model input data) were considered outliers and excluded from the map. As such, we ascertained that no prediction went beyond the performance of the model.

[1] The Mahalanobis distance (measure of distance between two points in the space defined by two or more correlated variables) is the distance between each sample and the macrobenthic community centroid in the multivariate space defined by the variables in the model.

## C. RESULTS

### 1. Community analysis

Based on Detrended Correspondence Analysis, Cluster Analysis and TWINSPAN, 690 samples were consistently assigned to eight sample groups (Table 5). In total 83 samples (11 %) were inconsistently grouped and were excluded from further analysis. All groups consisted of 23 (sample group B) to 228 samples (sample group F), except for sample group H, which consisted of no more than five samples. Group H was therefore excluded from further analyses.

An uneven relative distribution of the samples of each sample group over the macrobenthic communities and transitional species assemblages was found (Table 5). Because the major part of the group C samples (83 %) corresponded with the *A. alba* community, group C was here defined as the *A. alba* community. Likely, groups A (max. 58 %), E (max. 47 %) and G (max. 100 %) were defined as the *M. balthica*, *N. cirrosa* and the *O. limacina* community, respectively. The major part of groups D and F samples (96 % and 69 %, respectively) were part of TSAs, each representing a link between two “parent communities”. Sample group B could not be assigned to any community or TSA.

**Table 5: Relative distribution (%) of the samples of each multivariately defined sample group over the macrobenthic communities ([1] Van Hoey et al. 2004. [2] Degraer et al, 2003;). TSA 1, transitional species assemblage (TSA) between *A. alba* and *N. cirrosa* communities; TSA 2, TSA between *N. cirrosa* and *O. limacina* communities; TSA 3, TSA between *N. cirrosa* and intertidal communities.**

| | Multivariately defined sample groups | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| *Abra alba* community [(1)] | | | 83 | | | | |
| ← TSA 1 → [(1)] | | | 14 | 96 | 21 | 2 | |
| *Nephtys cirrosa* community [(1)] | | | | | 47 | 2 | |
| ← TSA 2 → [(1)] | | | 2 | 4 | 25 | 69 | |
| ← TSA 3 → [(1)] | | | | | 7 | 3 | |
| *Ophelia limacina* community [(1)] | | | 1 | | | 24 | 100 |
| *Macoma balthica* community [(2)] | 58 | 4 | 1 | 5 | | | |

### 2. Community habitat preferences

Clear differences in habitat preferences were found for all macrobenthic communities and for all environmental variables, taken into account (Figure 4). From the *M. balthica* community to the *O. limacina* community a preference for increasing median grain size was detected. Although less obvious, a similar positive relationship was found for depth, distance to the coast and slope. An opposite trend was detected considering sediment the mud content.

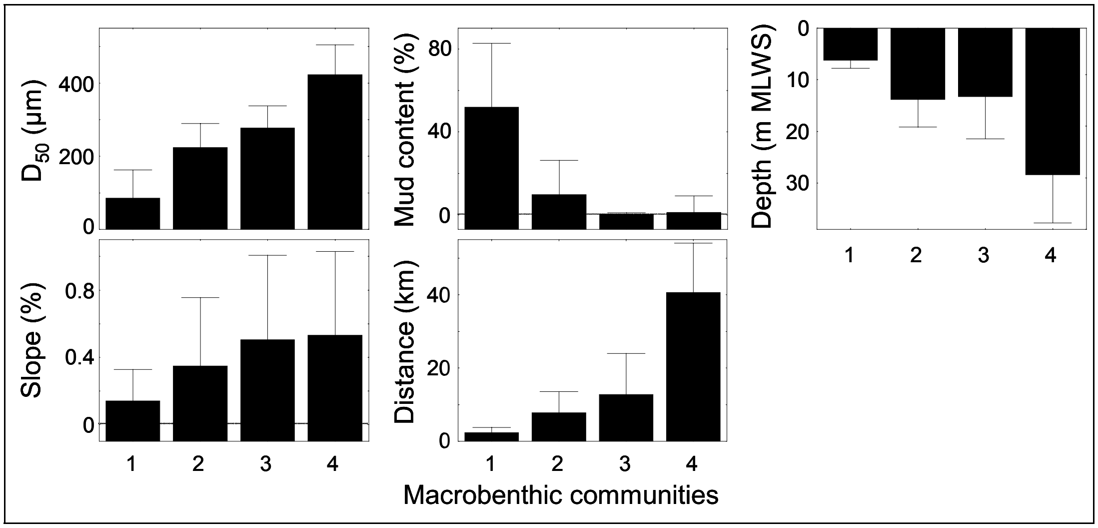


**Figure 4: Habitat preferences of all macrobenthic communities: 1, *Macoma balthica* community; 2, *Abra alba* community; 3, *Nepthys cirrosa* community; 4, *Ophelia limacina* community. Mean ± standard deviation.**

## 3. Community habitat suitability modeling

At first several combinations of environmental variables were used to set preliminar habitat suitability models.

Distance to the coast and slope were never taken into the preliminar models by the discriminant function analysis and were thus automatically rejected from further modelling exercises. As a result only three environmental variables were taken into the preliminar models: median grain size, sediment mud content and bathymetry, of which bathymetry only accounted for a minor predictive part. Because of (1) its relative low predictive power and (2) the non-causal relationship between depth and community structure, it was decided to exclude depth from the modelling exercise. The final model was thus restricted to the variability explained by median grain size and sediment mud content, extended with the interaction term between both (median grain size x sediment mud content). The correlation coefficient between those three variables was maximum [-0.579]. Since the threshold value of 0.75 was never exceeded, the variables were regarded as uncorrelated and were thus used in the final model.

The performance of the final model was tested by means of (1) cross-validation and (2) splitting the data into training cases (70 %) and testing cases (30 %). Both method revealed a very similar accuracy, indicative for a good model performance. It further allowed to include the whole dataset to set the final model.

Three discriminant functions (i.e. roots) were proposed. The first function, explaining 70 % of the variance, was mainly determined by the median grain size. Mud content was most relevant within the second discriminant function, accounting for 23 % of the variance. The third function (7 % of the variance) was dominated by the interaction term (median grain size x sediment mud content).

Four classification functions (i.e. one per macrobenthic community) were derived (Table 6).

**Table 6: Community specific weights of all variables taken into the classification functions. Cases are classified to the community rendering the highest score, by applying $S_i = w_{i(\text{Median grain size})}$*(Median grain size) + $w_{i(\text{Mud content})}$*(Mud content) + $w_{i(\text{Interaction term})}$*(Interaction term) + Constant, with i = community i.**

| | *Macoma balthica* community | *Abra alba* community | *Nephtys cirrosa* community | *Ophelia limacina* community |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Median grain size | 0.0759 | 0.0812 | 0.0908 | 0.1394 |
| Mud content | 0.4717 | 0.2581 | 0.2675 | 0.4150 |
| Interaction term | 0.0014 | 0.0014 | -0.0002 | -0.0003 |
| Constant | -18.4052 | -12.7750 | -14.0063 | -31.1189 |

The *a posteriori* accuracy of the final model is 77 % on average, with a minimum of 67 % (sample group A) and a maximum of 88 % (sample group G) (Table 7). The majority of the sample were thus classified into the correct community. Uncorrectly classified samples were generally assigned to a neighbouring community (*M. balthica* community ↔ *A. alba* community ↔ *N. cirrosa* community ↔ *O. limacina* community).

**Table 7: *A posteriori* accuracy and sample classification, rows: observed classifications and columns: predicted classifications.**

| | ***A posteriori* accuracy** | ***M. balthica* community** | ***A. alba* community** | ***N. cirrosa* community** | ***O. limacina* community** |
|---|---|---|---|---|---|
| *Macoma balthica* community | 71 % | 20 | 6 | 2 | 0 |
| *Abra alba* community | 67 % | 8 | 90 | 33 | 4 |
| *Nephtys cirrosa* community | 84 % | 0 | 4 | 108 | 17 |
| *Ophelia limacina* community | 88 % | 1 | 0 | 8 | 63 |
| Total | 77 % | 29 | 100 | 151 | 84 |

## 4. Habitat suitability maps

The habitat suitability could be reliably assessed for 53266 grid cells (i.e. 98.4 % of the BPNS): the prediction for the remaining 1.6 % was considered beyond the habitat suitability model performance (i.e. Mahalanobis distance > 3 SD from any macrobenthic community centroid, see Materials and Methods).

The habitat suitability for the four macrobenthic communities is clearly zoned throughout the BPNS (Figure 5: Predicted habitat suitability maps for the *Macoma balthica* community (A), the *Abra alba* community (B), the *N. cirrosa* community (C) and the *Ophelia limacina* community (D) in the BPNS. White, no data or prediction beyong model performance; Light grey, 0 % suitability; Black, maximum suitability. UTM 31N – WGS84 coordinates.). At first, a clear onshore-offshore gradient in habitat suitability can be discerned. The offshore benthic habitats are suited mainly for the *O. limacina* – *G. lapidum* community (maximum suitability: ≈ 100 %), while the *A. alba* community is expected to dominate the onshore area (maximum suitability: 98.3 %). The habitat of the *N. cirrosa* community is taking an intermediate position (maximum suitability: 79.4 %). A second longshore gradient can further be found in the onshore zone. In the western part of the onshore zone a clear dominance of the habitat of the *A. alba* community is found, whereas this community is expected to co-dominate the eastern part, together with the *M. balthica* community (maximum suitability: ≈ 100 %).

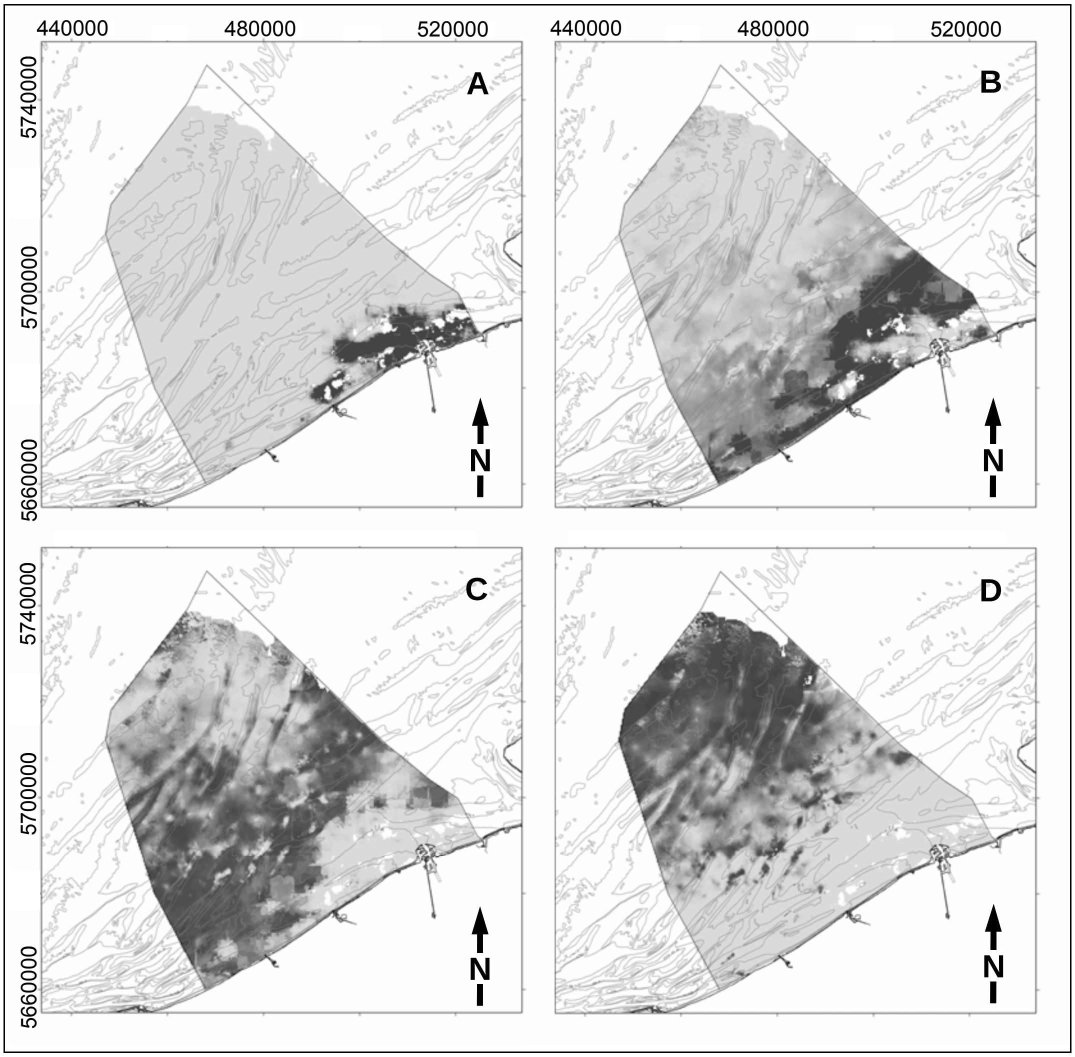


**Figure 5: Predicted habitat suitability maps for the *Macoma balthica* community (A), the *Abra alba* community (B), the *N. cirrosa* community (C) and the *Ophelia limacina* community (D) in the BPNS. White, no data or prediction beyong model performance; Light grey, 0 % suitability; Black, maximum suitability. UTM 31N – WGS84 coordinates.**

# V. Marine biological valuation of seabirds of the BPNS

Wouter Courtens & Eric W.M. Stienen

## A. INTRODUCTION

The BPNS is – despite its relatively small surface area – a highly important area for seabirds, not only for wintering birds but also for migrants and breeding birds (e.g. Seys *et al.*, 1999; Seys, 2001; Stienen & Kuijken, 2003). Being a bottleneck area for seabirds migrating from the northern breeding areas to the southern wintering areas, more than 5% of the biogeographical population of 12 species migrates through the southern part of the North Sea (Seys, 2001; Stienen & Kuijken, 2003). Also, the BPNS functions as a major feeding area for the internationally important tern colonies in the harbour of Zeebrugge (Alvarez, 2005, Stienen *et al.*, 2005).

The importance of the BPNS was acknowledged by the designation of three Marine Protected Areas in 2005. The delineation of these areas was based on a selection of species, namely the species that occur on the Annex I of the Bird Directive (Sandwich Tern, Common Tern and Little Tern) and species regularly occurring with more than 1% of the biogeographical population (Great-Crested Grebe, Little Gull, Common Scoter and Great Skua) (Haelters *et al.*, 2004). Although the study of Haelters *et al.* (2004) was very important in terms of conservation of threatened species, unlike this study it did not aim to valuate the broader ornithological importance of the BPNS. In the underlying study, a biological valuation map of the BPNS is presented, that not only takes into account internationally protected species, but also non-threatened and more widely distributed species of seabirds. The final result gives a good view of the relative ornithological importance of the different zones of the BPNS.

## B. DATA COLLECTION

### 1. Seabird counts in the Belgian part of the North Sea

The Research Institute for Nature and Forest conducts standardised ship-based surveys since September 1992. Until 2001 this was mainly done from public ferries and the RV Belgica, but since 2001, three fixed monitoring-routes were counted each month from the RV 'Zeeleeuw' (e.g. Seys, 2001). To determine the distribution, numbers and densities of seabirds in the BPNS, the data collected between September 1992 and December 2004 were analysed. Additionally, the data from the counts in 2005 were used to determine the species-diversity (see further). Thus, the compiled dataset does comprise data of standardised counts that are well distributed both temporally (both between years and within years) and spatially on the BPNS (Annex C).

Both swimming and flying birds were counted by a standardised strip-transect-method (Tasker *et al.*, 1984). All swimming birds that are within a distance of 300 m and in an angle of 90° forward from the study-vessel were counted in intervals of 10 minutes. Flying birds were counted using a snapshot method (Komdeur *et al.*, 1992). All flying birds within a distance of 300 m and an angle of 90° forward from the study-vessel were counted every minute. In order to compensate for missed small and dark birds, the mean density of swimming birds has been multiplied with an internationally accepted correction factor (hoeveel?) (Stone *et al.*, 1995).

The results of these counts were transformed into densities by taking into account the speed of the research-vessel. All counts were reduced to the spatial mid points of the concerned 10-minute tracks. These midpoints were called position keys or 'poskeys' and are displayed in the dataset in degrees northern latitude and eastern longitude and hold the local densities of all species (number per square km). If the ship changed its course within a 10-minute count, the counts relate to a shorter period. To avoid that counts in very short periods of time would bias the calculation of bird densities, all poskeys in which less than 1 km was covered were omitted. Since ferry counts may result in an underestimation of the densities of certain species (e.g. alcidae and divers) because of the higher speed and the height of the observation platform, the data collected from ferries were not retained in the processed dataset. After these selections, data of 10.808 poskeys were retained. For the calculation of the number of species per 3x3 km-square all counts (also counts from ferries and those of 2005) were used (15.908 poskeys).

## 2. Data analysis

- SELECTION OF SPECIES

As a first step, all observations of non-seabirds were omitted from the dataset. A seabird was defined as 'a species of which at least part of the population forages at sea in a certain part of the year' (adapted from Furness & Monaghan, 1987). Between 1992 and 2005, 47 seabird species were recorded during ship-based counts on the BPNS (Table 1 and 2 in Annex D). For further data analysis, this species list was divided into 'common' and 'rare' seabirds. As a distinguishing criterion, a 'common' seabird was defined as a species that was observed in more than 1% of the poskeys (i.e. > xxx poskeys), a 'rare' seabird as one that was seen in less than 1% of the poskeys (Table 1 in Annex D). Finally, 18 common seabirds were retained. This division is also defensible when the total number of birds of each species is taken into account (Table 2 in Annex D).

The smaller divers (notably Red- and Black-throated Diver) were grouped and analysed together as diver sp. since both species are not always easily distinguished at sea and a lot of the observations are noted as diver sp. This elevates the precision of the final result (more observations), while it does not necessarily have consequences for the valuation since the proportion of the concerned species (Red-throated Diver) in the global group of diver sp. is very high (95,6% of all smaller divers identified were Red-throated Divers and 4,4% Black-throated Divers, Vanermen *et al.*, 2005)[2].

- INTERPOLATION OF DATA

Annex C and E show that the observer effort is unevenly distributed over the BPNS. On the one hand this reflects a bias of the fixed monitoring routes of the last years, on the other hand some areas cannot be reached because they are too shallow or because they are to far away to fit in a one-day schedule. Therefore, a spatial interpolation was applied to obtain maps that cover the complete BPNS. To account for confounding effects of within-year fluctuations in densities and distribution of seabirds (some species occur the whole year, others only in winter or during the breeding season), an *a priori* selection of the months in which a certain species occurs in the highest densities was made. This procedure is based on the idea that the occurrence of a species in a certain density in a certain location is a reflection of the suitability of this location at that time. Therefore, for each species the mean density per month was calculated (Annex F). For the

[2] In the text and the figures Red-throated Diver is retained as the name for this group.

interpolation only the data were retained from the months in which the mean density was at least 25% of the value of the month with the maximal density (Annex G). When less than five months fulfilled this condition (which was especially the case in species that have a very high peak density in one or two months, e.g. Sandwich and Common Tern), the five months with the highest densities were selected.

The final dataset was interpolated for each species separately using the Spatial Analyst package of ArcGis 9.0. The interpolation method used was Inverse Distance Weighting and a density raster of 500 by 500m was created for each species. By using this algorithm, the mid point of each raster cell got the mean density of the concerned species of the 24 poskeys closest to it (ook indien zeer veraf?), the contribution of each poskey to the final value is inversely related to the distance that poskey is from the mid point. For further analysis, these rasters were converted into a grid with cells of 3x3 km (hoe werd dit gedaan?). This dimension was chosen because it matches well with the mean distance covered by boat in 10 minutes (i.e. 2.98 km).

## C. APPLICATION OF VALUATION CRITERIA ON SEABIRD DATA

The global underlying methodology for the valuation of the BPNS for seabirds is defined in chapter III and is based on the valuation criteria stipulated in chapter II. Not all these questions could be answered for seabirds because of some limitations of the data available and particularities of the seabird community. There are for example no data available on the genetic structure of the seabird population on the BPNS and criteria such as 'are there habitats formed by keystone-species' are irrelevant when considering seabirds. In contrast to other ecosystem components, no great importance was attached to rare species since they do not reflect the biological value of the area. The occurrence of rare seabirds (listed in Annex D) on the BPNS does not say anything about the value of the stretch of sea where they are observed since they are only stray birds that should not really occur there (but they are no alien species either). Only to answer the question on species richness, rare seabirds were included in the calculations.

Selecting the questions this way, four valuation assessment questions were retained to build the final seabird valuation map:

Is the subzone characterized by high counts of many species?
Is the abundance of a certain species very high in the subzone?
Is a high percentage of a species population located within the subzone?
Is the species richness in the subzone high?

### 1. Answer to question: Is the subzone characterized by high counts of many species?

The cells of the extrapolated density-rasters of each species were divided in 10 classes using the quantile classification-method in ArcGis 9.0. By doing this, each class contains the same number of raster-cells. These classes got values of 1 (lowest densities) to 10 (highest densities). Raster-cells in which a given species was not observed got a value of 0. Next, for each raster-cell the values of all species were summed up (Annex H). Then, for each grid-cell of the 3x3 km-grid, the mean value of the enclosed raster-cells was calculated. Finally, these values were divided into 5 classes, again using the quantile classification-method, so that all classes contain an equal number of grid-cells (Annex I).

### 2. Answer to question: Is the abundance of a certain species very high in the subzone?

Based on the interpolated density-rasters, the mean number of each common species present in the BPNS was calculated (Annex J). Subsequently, for each species, the mean density and the mean number of birds (wat is het verschil?) was calculated for each 3x3 km-gridcell. Based on these figures, a map was created showing the proportional importance of a given subzone for each species (Annex K).
Some species obviously occur very aggregated and locally reach very high densities, whereas others occur more evenly distributed over the BNPS. To account for this difference, an 'aggregation-coefficient' was calculated by dividing the total percentage of the 5% of grid-cells with the highest densities by the total number of grid-cells in which the species was recorded (Annex J). For each species, an 'aggregation-map' was created by multiplying the proportional importance of each grid-cell (given in Annex K) by its aggregation-coefficient. Finally the values of the 18 species were summed for each grid-cell to obtain a single aggregation map (Annex L).

### 3. Answer to question: Is a high percentage of a species' population located within the subzone?

For each species, the percentage of the biogeographical population occurring in each cell of the 3x3 km-grid was calculated. The biogeographical populations of the species were derived from Delany & Scott (2005) and from Burfield & Van Bommel (2004). Based on these values, biopopulation-maps were created for each species (Annex M). Annex N gives the aggregated 'biopopulation-map'. This map was created by multiplying the value of each grid-cell of the biopopulation-maps of each species by its aggregation-coefficient and by summing up the resulting values for the 18 species for each grid-cell.

### 4. Answer to question: Is the species richness in the subzone high?

For each grid-cell, the number of seabird species observed in the field was determined (Annex O). Given the difference in observer effort (number of $km^2$ surveyed per grid-cell, Annex E) between the grid-cells, this is not a realistic representation of the situation. Therefore, the observed number of species was corrected by applying a logistic regression analysis in which besides the variable 'number of kilometres surveyed', also 'distance to the coast' and 'mean depth' in each grid-cell was taken into account. The last two variables were taken into account to correct for possible differences in species richness between coastal and non-costal grid-cells as well as for possible relations between species' occurrences and sandbanks. Because 'distance to the coast' and 'mean depth' were strongly correlated and given the fact that 'distance to the coast' explained more of the variance than 'mean depth', only 'distance to the coast' was finally retained in the regression. The regression equation is as follows (Equation 1):

Equation 1: $N\ species^{exp} = 1,817 + 7,898 * \log (n\ km) - 0,1405 * \text{distance to coast} + 0,0012 * (\text{distance to coast})^2$

Annex P gives the modelled number of species per 3x3 km-grid-cell.

As a last step, the deviation of the modelled expected value relative to the number of species actually observed in the field was calculated for each grid-cell (proportional deviation, Equation 2).

Next, for each grid-cell the expected number of species for a fixed distance of 400 km monitored was corrected with this value to obtain the final biodiversity (Equation 3) per grid-cell:

Equation 2: Proportional deviation = $[(N\ species^{obs} - N\ species^{exp}) / N\ species^{exp}] * 100$

Equation 3: Biodiversity = $N\ species^{exp(400\ km)} + [(N\ species^{exp(400\ km)} / 100) * \text{proportional deviation}]$

Annex Q gives the final biodiversity-map.

## *D. MARINE BIOLOGICAL VALUATION MAP OF SEABIRDS OF THE BPNS*

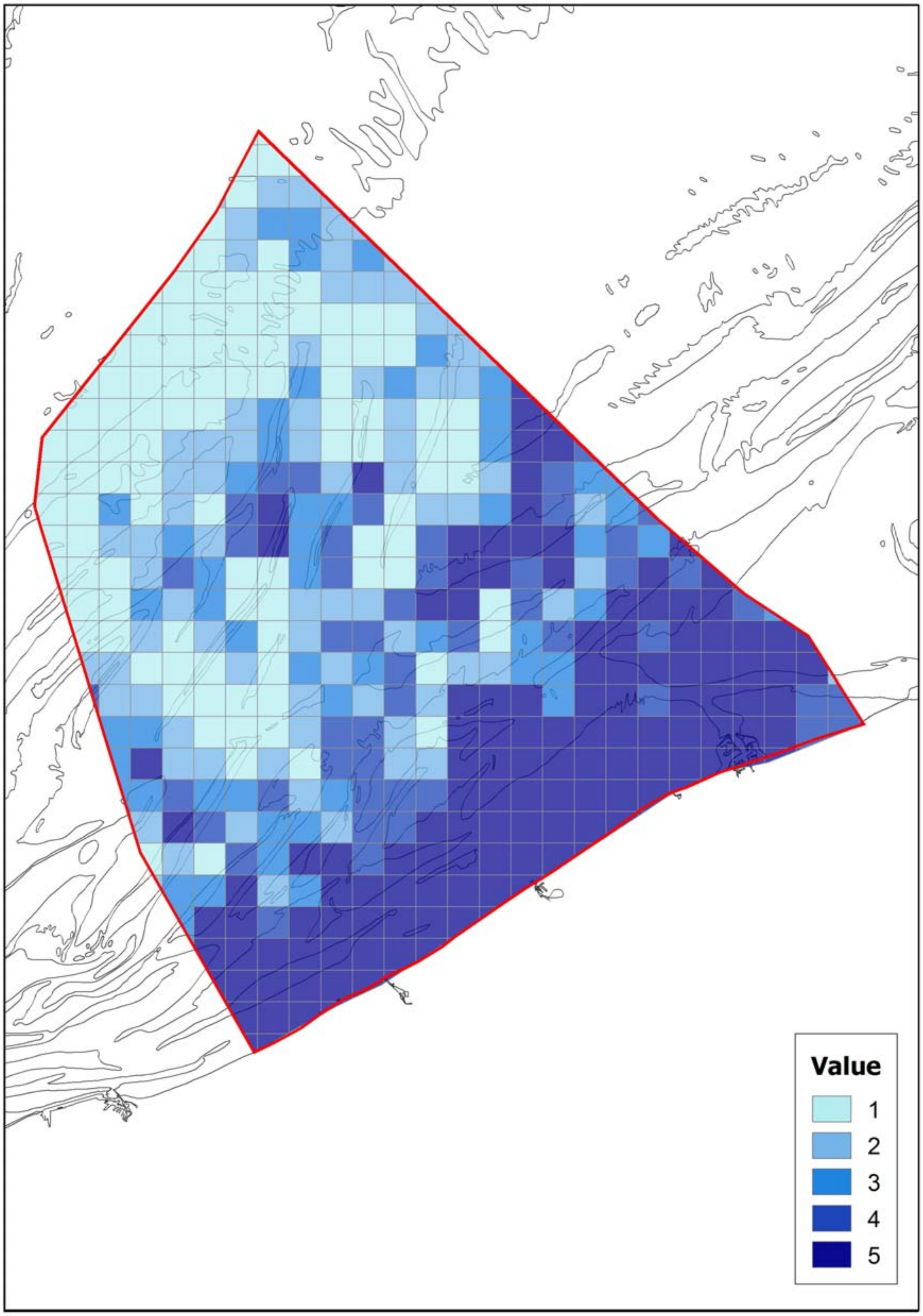


**Figure 6: Marine biological valuation map of seabirds of the BPNS.**

## *E.* *RELIABILITY OF RESULTS*

As a direct consequence of the uneven distribution of the datapoints on the BPNS, due to differences in observer effort (Annexes C and E), the data for the different grid-cells are not equally reliable. In less well sampled areas the interpolation made use of datapoints quite far from the mid point (up to xxx m) and in those areas it is thus possible that the values do not accurately reflect the actual situation. This is especially the case for the borders of the BPNS that were, despite an effort to count more often in these areas during the last two years, less well sampled compared to the rest of the BPNS. Therefore, a reliability score was given to each grid cell, ranging from 1 (least reliably, < 10 km² surveyed) to 3 (most reliable, > 30 km² surveyed), based on the categories given in Annex E. As a rule, one can expect grid cells with a score 2 to 3 (more than 10 $km^2$ surveyed) to be sufficiently reliable. The reliability map for the seabird valuation can be found in Annex R.

## *F.* *DISCUSSION OF MAPS*

The ultimate valuation map (Figure 6) clearly shows the high ornithological value of the coastal zone (Vlaamse Banks, Zeelandbanks and Vlakte van de Raan). This zone has since long been recognised as being important for seabirds on the BPNS both as foraging area for breeding birds and for wintering birds (e.g. Seys *et al.*, 1999; Seys, 2001; Stienen & Kuijken, 2003; Haelters *et al.*, 2004). The map, however, throws a new light on the value of more offshore regions. Where earlier studies failed to identify these areas as particularly important for seabirds, the valuation method used in this study clearly pinpoints the higher ornithological value of the Thorntonbank, the waters north of the Vlakte van de Raan and parts of Hinderbanks.

A word of caution regarding the numbers of seabirds occurring on the BPNS calculated to create the aggregation maps (Annexes K and L) and the biopopulation-map (Annexes M and N) has to be put here. These numbers are to be regarded as the mean number of birds that are present in the selected months and not as maxima nor as the total number of birds present any one time. The numbers presented here are very useful for biological valuation, but do not reflect the real seabird densities, since peak numbers are often levelled off. Also, these numbers do not take into account the turnover rate of migrating seabirds. For example: 40 to 100% of the biogeographical population of Little Gull is crossing the BPNS, both during spring and autumn (Seys, 2001; Stienen & Kuijken, 2003), but interpolated values presented here only concern 1,2 % of the biogeographical population.

# VI. Marine biological valuation of macrobenthos of the BPNS

Sofie Derous, Pieter Deckers, Klaas Deneudt & Steven Degraer

## A. INTRODUCTION

Before this study no method to determine the biological value of the macrobenthos existed. Valuation assessments were always based on a thorough analysis of the available point data combined with "best expert judgement". A first attempt to develop an objective biological valuation method for the macrobenthos of the BPNS was made by Gheerardyn (2002). Gheerardyn (2002) based his valuation method on the criteria used during the development of terrestrial biological valuation maps of Belgium (De Blust et al., 1985) and after translation from the terrestrial to the marine environment, four main criteria (divided in subcriteria) were selected: **rarity** (subdivided in 'rarity of species' and 'rarity of communities'), **biological quality** (subdivided in 'structural diversity of macrobenthos', 'functional role of macrobenthos as food source or as community structuring factor', 'indicator for pollution or eutrophication' and 'habitat diversity'), **vulnerability** (subdivided in 'vulnerability of macrobenthos to pollutants', 'vulnerability of macrobenthos to physical disturbance' and 'vulnerability of habitats') and **replaceability**. Due to the unavailability of certain data, only a few of these criteria and subcriteria could be evaluated at that time. The author mentioned that translation of the criteria to the marine environment was not easy and that the criteria used need to be re-evaluated and adjusted in the future. The present valuation exercise took these criteria as a starting point, for revision and adaptation during an international workshop (see chapter II).

## B. DATA COLLECTION

### 1. Macrobenthos data in the Belgian part of the North Sea

The macrobenthos of the BPNS was intensively sampled and studied during the periods 1976-1986 and 1994-2001. The samples were collected in the framework of different research projects, each with their own purpose. As a consequence the sampling intensity in both periods is not proportional distributed over the BPNS. During both periods research was mainly focused on the western Coastal banks and the Vlaamse banks. Next to these areas several samples were taken in the eastern Coastal banks, the Zeeland banks and the Hinder banks during both periods. While the sampling activities were mostly focused on the sandbank tops during the period 1976-1986, many samples were taken in the gullies between the sandbanks in the period 1994-2001.

All samples were collected with a Van Veen grab which allows an easy collection of the macrobenthos of the sea bottom (surface area: 0.1 or 0.12 m$^2$; penetration depth: 10 cm). All macrobenthic individuals are separated from the sediment by using a 1 mm sieve and are fixated and conserved using an 8 % formaldehyde-seawater solution. In the 1976-1986 period an alternative sieving procedure (0.86 mm sieve) was used and the sample was also fixated before sieving. This resulted in samples with more and smaller macrobenthic individuals compared to the samples collected from 1994 onwards. This could influence the comparison of these older samples with the more recent ones (Degraer et al., in press) and therefore only the samples collected in the period 1994 until now were considered during the following analysis.

All samples were analysed by identifying the species present in the sample and by counting the number individuals per sample (i.e. the abundance of each species). This information was put in the MS-ACCESS MACRODAT Database (hosted by SMB).

The BPNS was divided into 250x250 m grid cells for the valuation of the macrobenthos and there were 725 grid cells for which macrobenthic information on species richness and density was available. For all grid cells information on the expected macrobenthic community (based on the results of the predictive model, see Chapter IV) was available. The distribution of the sampling effort (number of replicates per grid cell) is given in annex S. This map shows clearly that most sampling occurred in the coastal area (mostly western coast) and around the Vlaamse banks.

The data used for biological valuation of the macrobenthic component is a subset of the MACRODAT database. The MACRODAT database was transferred to VLIZ for extraction of the data to be used in the valuation, for carrying out the calculations (i.e. valuation algorithms) on the data in the database and for linking the data to the geographical layers and producing the end products to be displayed in the online atlas and the report. In collaboration with SMB VLIZ performed some basic quality control on the used dataset by checking taxonomy, geographical coordinates and temporal series of samples.

## 2. Data analysis

- SELECTION OF SPECIES

Taxa used were checked against standard taxonomy as described in the ERMS list (European Marine Register of Species), hereby avoiding the use of synonymous taxa in the calculations. Some taxa were grouped at higher taxonomic levels in order to get consistent taxonomic groups. No distinction was made between adult or juvenile specimens and both were included in the analysis as individuals of the same species.

In order to be able to take into account the distinction between temporal series of samples, separate samples at distinct stations and true replicates, some additions to the database were necessary. All visits (spread in time) to a certain station were linked to a unique place name with a fixed coordinate arbitrarily taken as the mean longitude and latitude of the samples. The link between the point data and the 250x250 m grids was done at the level of these place names, applying the data of all place names within a certain grid cell to that entire grid cell.

Calculations of the assessment questions were done by means of a dynamic series of dependent queries on the database, always resulting in a single result table with the division in classes for each question.

- INTERPOLATION OF DATA

Chapter IV explains the methodology for the prediction of macrobenthic communities based on sediment characteristics (median grain size and silt-clay percentage). As there are many data available on these sediment parameters for the BPNS it is possible to create full-coverage maps for them by applying interpolation techniques. The Habitat model allows the prediction of the spatial distribution of the habitat suitability for the macrobenthic communities based on these full-coverage sediment maps.

## C. *APPLICATION OF VALUATION CRITERIA ON MACROBENTHOS DATA*

The methodology used for the valuation of the macrobenthos occurring in the BPNS is defined in chapter III and is based on the valuation criteria stipulated in chapter II. The selection of the assessment questions that could be answered for macrobenthos was based on the available data for macrobenthos and on the nature of the questions itself (some are more relevant to macrobenthic communities than others). In contrast to the valuation of seabirds, assessment questions relating to the rarity of certain macrobenthos species were included in the valuation of macrobenthos. The assessment of rare species is relevant to the biological value of a subzone because the macrobenthos has a limited dispersion capacity and they are not expected to be recorded during “accidental passage” through the Belgian marine waters. Some species were found in the macrobenthos species list of the BPNS which were wrongly determined as macrobenthos species (e.g. hyperbenthic or epibenthic species, demersal fish species) and these were excluded from the valuation exercise as were synonyms of macrobenthos species. Doing this also decreased the number of species included in the rare species list.

Nine valuation assessment questions were retained to build the final macrobenthos valuation map:

Is the subzone characterized by high counts of many species?
Is the abundance of a certain species very high in the subzone?
Is the subzone characterized by the presence of many rare species?
Is the abundance of rare species high in the subzone?
Is the abundance habitat-forming species high in the subzone?
Is the abundance of ecologically significant species high in the subzone?
Is the species richness in the subzone high?
Are there distinctive/unique communities present in the subzone?

Seven questions could be applied on the macrobenthos point data from MACRODAT, while only one question (“Are there distinctive/unique communities present in the subzone?”) could be applied on the predicted macrobenthic community data (see chapter IV and “interpolation of data” paragraph above). Only this question creates a full-coverage value map for the macrobenthos, while the other questions give additional value information for certain points on the map.

### 1. Answer to question: Is the subzone characterized by high counts of many species?

To answer this question the species list of all macrobenthos species which are regularly occurring in the BPNS were separated from the rare macrobenthic species list. Rare species were defined as species which occur in less than 5% of the grid cells with data on macrobenthos. This resulted in a list of 131 rare species and 71 regularly occurring species (see Table 10 and Table 8). Then the average density of every regularly occurring species was calculated per grid cell, as follows:

1. the density of each species per sample was calculated as the average density of all replicates per sample
2. the density of each station was calculated as the average density of all samples per station
3. the density of each grid cell was calculated as the average density of all stations within a grid cell

Per species, the average density per grid cell was then divided into 5 classes. All these values were summed to get to a final result for all species together per grid cell and again divided into 5 classes (based on the range of the values). The result of this analysis is shown in Annex T.1.

**Table 8: list of macrobenthos species which are regularly occurring in the BPNS.**

| | | | |
|---|---|---|---|
| *Abra alba* | *Ensis* species | *Montacuta ferruginosa* | *Scoloplos armiger* |
| Actinaria species | *Eteone longa* | *Mysella bidentata* | *Sigalion* species |
| *Ampelisca brevicornis* | *Eumida sanguinea* | *Mytilus edulis* | *Spio* species |
| *Aonides* species | *Gastrosaccus spinifer* | *Nassarius reticulatus* | *Spiophanes bombyx* |
| *Atylus falcatus* | *Glycera alba* | *Nephtys cirrosa* | *Spisula subtruncata* |
| *Atylus swammerdami* | *Glycera lapidum* | *Nephtys hombergii* | *Sthenelais boa* |
| *Autolytus* species | *Harmothoë (Malmgrenia)* species | *Nephtys longosetosa* | *Tellina fabula* |
| *Bathyporeia* species | *Hesionura elongata* | *Nereis longissima* | *Tellina pygmea* |
| *Bodotria* species | *Heteromastus filiformis* | *Notomastus latericeus* | *Tellina tenuis* |
| *Capitella* species | *Lanice conchilega* | Oligochaeta species | *Thia scutellata* |
| Cirratulidae species | *Leucothoe incisa* | *Ophelia limacina* | *Urothoe brevicornis* |
| *Crangon crangon* | *Liocarcinus (Polybius) holsatus* | *Ophiura albida* | *Urothoe poseidonis* |
| *Crepidula fornicata* | *Lunatia (Polinices) alderi* | *Ophiura ophiura* | *Venerupis pullastra* |
| *Diastylis* species | *Macoma balthica* | *Owenia fusiformis* | |
| *Diogenes pugilator* | *Magelona species* | *Pariambus typicus* | |
| *Donax vittatus* | *Melita (Abludomelita)* species | *Pontocrates altamarinus* | |
| *Echinocardium cordatum* | *Microphthalmus similis* | *Pseudocuma* species | |
| *Echinocyamus pusillus* | *Microprotopus maculatus* | *Scolelepis bonnieri* | |

## 2. Answer to question: Is the abundance of a certain species very high in the subzone?

The “high abundance of certain species” assessment question combines the density of a number of species with the level of aggregation of those species.
The average density over the whole study area (=X) was calculated for every regularly occurring species. Then the average density of every species was calculated for every grid cell (=Xi). This allowed the determination of the Xi/X ratio of every species in every grid cell.

Per species the top 5% grid cells with the highest Xi/X ratio were determined and the percentage of the average density present in these top 5% cells was compared to the total summed average density over all grid cells was calculated for every species (=Y). The aggregation coefficient (Y/Z) was calculated for each species by dividing the value Y by the number of grid cells in which that species occurred (=Z). Table 9 gives an overview of the aggregation coefficient of each regularly occurring species.

The values Xi per species were divided into five classes based on the range of the values. These classes were then multiplied with the species specific aggregation coefficients (Y/Z). Per grid cell the results for all species were summed to get one total value. For the final result these values were again divided into 5 classes. The result of this analysis is shown in Annex T.2.

**Table 9: ratio Y, aggregation coefficient Y/Z and number of grid cells in which the species occurs (=Z) for all regularly occurring species.**

| Species | Y/Z | Y | Z | Species | Y/Z | Y | Z |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Microphthalmus similis* | 2,629 | 99,9 | 38 | *Ophiura albida* | 0,823 | 85,6 | 104 |
| *Lunatia (Polinices) alderi* | 2,474 | 98,9 | 40 | *Nephtys longosetosa* | 0,765 | 68,8 | 90 |
| *Crepidula fornicata* | 2,390 | 98,0 | 41 | *Pariambus typicus* | 0,763 | 90,1 | 118 |
| *Diogenes pugilator* | 2,344 | 98,5 | 42 | *Montacuta ferruginosa* | 0,746 | 74,6 | 100 |
| *Pseudocuma* species | 2,268 | 97,5 | 43 | *Eumida sanguinea* | 0,722 | 88,8 | 123 |
| *Microprotopus maculatus* | 2,195 | 96,6 | 44 | *Pontocrates altamarinus* | 0,718 | 61,0 | 85 |
| *Tellina pygmea* | 2,178 | 95,8 | 44 | *Nereis longissima* | 0,715 | 70,0 | 98 |
| *Heteromastus filiformis* | 2,091 | 98,3 | 47 | *Pectinaria koreni* | 0,705 | 77,5 | 110 |
| *Hesionura elongata* | 2,054 | 98,6 | 48 | *Eteone longa* | 0,641 | 79,4 | 124 |
| *Sigalion* species | 1,861 | 94,9 | 51 | *Glycera alba* | 0,613 | 69,9 | 114 |
| *Echinocyamus pusillus* | 1,835 | 95,4 | 52 | *Diastylis* species | 0,584 | 77,0 | 132 |
| *Crangon crangon* | 1,823 | 92,9 | 51 | *Capitella* species | 0,581 | 80,2 | 138 |
| *Tellina tenuis* | 1,820 | 91,0 | 50 | Oligochaeta species | 0,569 | 75,1 | 132 |
| *Bodotria* species | 1,798 | 95,3 | 53 | *Notomastus latericeus* | 0,530 | 79,0 | 149 |
| *Liocarcinus (Polybius) holsatus* | 1,615 | 93,7 | 58 | *Urothoe poseidonis* | 0,525 | 79,3 | 151 |
| *Mytilus edulis* | 1,569 | 92,6 | 59 | *Ensis* species | 0,500 | 82,4 | 165 |
| *Atylus swammerdami* | 1,563 | 93,8 | 60 | Actinaria species | 0,469 | 74,5 | 159 |
| *Ampelisca brevicornis* | 1,505 | 90,3 | 60 | *Lanice conchilega* | 0,467 | 89,7 | 192 |
| *Aonides* species | 1,499 | 89,9 | 60 | *Phyllodoce maculata-mucosa* | 0,429 | 81,4 | 190 |
| *Atylus falcatus* | 1,413 | 86,2 | 61 | *Spisula subtruncata* | 0,405 | 86,7 | 214 |
| *Venerupis pullastra* | 1,389 | 94,4 | 68 | Cirratulidae species | 0,402 | 85,2 | 212 |
| *Thia scutellata* | 1,304 | 76,9 | 59 | *Mysella bidentata* | 0,386 | 78,4 | 203 |
| *Harmothoë (Malmgrenia)* species | 1,198 | 86,3 | 72 | *Abra alba* | 0,375 | 79,5 | 212 |
| *Pholoe minuta* | 1,198 | 87,4 | 73 | *Tellina fabula* | 0,354 | 67,9 | 192 |
| *Poecilochaetus serpens* | 1,126 | 90,1 | 80 | *Gastrosaccus spinifer* | 0,348 | 74,8 | 215 |
| *Autolytus* species | 1,050 | 82,9 | 79 | *Urothoe brevicornis* | 0,331 | 56,7 | 171 |
| *Nassarius reticulatus* | 1,023 | 86,0 | 84 | *Magelona* species | 0,304 | 86,0 | 283 |
| *Macoma balthica* | 1,016 | 82,3 | 81 | *Ophelia limacina* | 0,275 | 53,9 | 196 |
| *Donax vittatus* | 0,985 | 83,7 | 85 | *Spio* species | 0,253 | 58,1 | 230 |
| *Leucothoe incisa* | 0,954 | 78,2 | 82 | *Echinocardium cordatum* | 0,219 | 45,5 | 208 |
| *Melita (Abludomelita)* species | 0,923 | 86,7 | 94 | *Spiophanes bombyx* | 0,187 | 76,6 | 410 |
| *Sthenelais boa* | 0,912 | 82,1 | 90 | *Scoloplos armiger* | 0,174 | 68,7 | 394 |
| *Ophiura ophiura* | 0,908 | 74,5 | 82 | *Bathyporeia* species | 0,173 | 57,9 | 334 |
| *Glycera lapidum* | 0,881 | 74,9 | 85 | *Nephtys hombergii* | 0,154 | 41,3 | 269 |
| *Owenia fusiformis* | 0,829 | 83,8 | 101 | *Nephtys cirrosa* | 0,040 | 22,6 | 566 |
| *Scolelepis bonnieri* | 0,824 | 79,1 | 96 | | | | |

### 3. Answer to question: Is the subzone characterized by the presence of many rare species?

131 rare species were found for the BPNS. For each grid cell it was determined how many rare species (Table 10) were present, as follows:

- the number of rare species per sample was calculated by summing the numbers of rare species of each replicate per sample and divide this sum by the number of replicates per sample

- the number of rare species of each station was calculated by summing the numbers of rare species of each sample per station and divide this sum by the number of samples per station
- the number of rare species of each grid cell was calculated by summing the numbers of rare species of each station per grid cell and divide this sum by the number of stations per grid cell

Grids where no rare species occurred were put in class 1. The grid cells where rare species occurred were classified into 4 species richness classes (2-5) based on the range of these values. The result of this analysis is shown in Annex T.3.

**Table 10: list of rare macrobenthos species of the BPNS.**

| | | | |
|---|---|---|---|
| *Abra prismatica* | *Eteone spetsbergensis* | *Malacoceros fuliginosa* | *Polydora* species |
| *Aequipecten opercularis* | *Eulalia bilineata* | *Megaluropus agilis* | *Polygordius appendiculatus* |
| *Ampharete acutifrons* | *Eulalia viridis* | *Modiolus modiolus* | *Pomatoceros triqueter* |
| *Ampharete balthica* | *Eumida bahusiensis* | *Monoculodus carinatus* | *Pontocrates arenarius* |
| *Amphilochus neopolitanus* | *Eunoë nodosa* | *Mya truncata* | *Portumnus latipes* |
| *Amphiura brachiata* | *Eurydice affinis* | *Nephtys assimilis* | *Protodorvillea kefersteini* |
| *Amphiura filiformis* | *Eurydice pulchra* | *Nephtys caeca* | *Psammechinus miliaris* |
| *Anoplodactylus petiolatus* | *Eurydice spinigera* | *Nephtys Kersivalensis* | *Pseudoparatanais batei* |
| *Aora typical* | *Euzonus flabelligerus* | *Nereis irrorata* | *Pygospio elegans* |
| *Aphrodita aculeate* | *Gammarus* species | *Nymphon brevirostre* | *Sabellaria spinulosa* |
| *Apseudes latreillii* | *Gastrosaccus sanctus* | *Ophiodromus flexuosus* | *Scalibregma inflatum* |
| *Arca lacteal* | *Gattyana cirrosa* | *Ophistodonta pterochaeta* | *Scolelepis foliosa* |
| Archiannelida species | *Glycera convoluta* | *Orbinia* species | *Scolelepis squamata* |
| *Arenicola marina* | *Goniadella bobretzkii* | *Orchomene* species | *Sphaerosyllis hystrix* |
| *Aricidea minuta* | *Hippomedon denticulatus* | *Pagurus bernhardus* | *Sphenia binghami* |
| *Astarte elliptica* | *Hyale nilssoni* | *Panoploea (Iphimedia) minuta* | *Spiophanes kröyeri* |
| *Asterias rubens* | *Idotea linearis* | *Paraonis fulgens* | *Spisula elliptica* |
| *Atylus vedlomensis* | *Idotea metallica* | *Pecten maximus* | *Stenothoe marina* |
| *Barnea candida* | *Ione thoracica* | *Perioculodes longimanus* | *Sthenelais marina* |
| *Callianassa* species | *Iphinoe tenella* | *Petricola pholadiformis* | *Streblospio benedicti* |
| *Calliopius laeviusculus* | *Jassa marmorata* | *Phaxas pellucidus* | *Streptosyllis websteri* |
| *Cerebratulus* species | *Jassa pusilla* | *Pholoe pallida* | *Syllis gracilis* |
| Chaetognatha species | *Laevicardium crassum* | *Phtisica marina* | *Synchelidium haplocheles* |
| *Chiton* species | *Leucothoe lilljeborgii* | *Phyllodoce groenlandica* | *Synchelidium maculatum* |
| *Corophium species* | *Liocarcinus (Polybius) arcuatus* | *Phyllodoce laminosa* | *Tanaissus lilljeborgi* |
| *Corystes cassivelaunus* | *Liocarcinus (Polybius) pusillus* | *Phyllodoce rosea* | *Travisia forbesii* |
| *Crangon allmanni* | *Lumbrineris fragilis* | *Pilumnus hirtellus* | *Typosyllis armillaris* |
| *Cumopsis goodsiri* | *Lumbrineris latreilli* | *Pinnotheres pisum* | *Upogebia deltaura* |
| Decapoda species | *Lunatia (Polinices) catena* | *Pisidia longicornis* | *Urothoe elegans* |
| Epitoniidae species | *Macropodia linaresi* | *Pisione remota* | *Urothoe marina* |
| *Eteone barbata* | *Macropodia rostrata* | *Podarkeopsis helgolandica* | *Urothoe pulchella* |
| *Eteone flava* | *Macropodia* species | *Poibuis henslowi* | *Westwoodilla caecula* |

| | | | |
|---|---|---|---|
| *Eteone foliosa* | *Maerella tenuimana* | *Polinices polianus* | |

### 4. Answer to question: Is the abundance of rare species high in the subzone?

For each grid cell it was determined what the total density of all rare species (Table 10) occurring in that cell is. Grids where no rare species occurred were put in class 1. The grid cells where rare species occurred were classified into 4 density classes (2-5) based on the range of the total density. The result of this analysis is shown in Annex T.4.

### 5. Answer to question: Is the abundance of habitat-forming species high in the subzone?

*Lanice conchilega* is a tubeworm occurring on the BPNS which is known to build small reefs on the seabed. These reefs give structure to the habitat, which attracts other species (Van Hoey et al., 2002; Van Hoey, 2006).

There are 192 grid cells in which the species *Lanice conchilega* occurs. For each grid cell the density of this species was determined. Grid cells where the species did not occur were put in class 1, while the other grid cells were classified into classes 2-5 (according to the range of the density values). The result of this analysis is shown in Annex T.5.

### 6. Answer to question: Is the abundance of ecologically significant species high in the subzone?

Ecologically significant species are species which among other constitute important food sources for higher trophic levels or species which area important predators or bioturbators. For the macrobenthos *Abra alba* and *Spisula subtruncata* were selected because they area important food sources of the Common Scoter (Melanitta nigra) in the BPNS (Offringa, 1991; Degraer et al., 1999).

The species *Abra alba* and *Spisula subtruncata* occur in respectively 212 and 214 grid cells.For each grid cell the density of both species was determined. Grid cells where a species did not occur were put in class 1, while the other grid cells were classified into classes 2-5 (according to the range of the density values for one species). Then the scores for both species were summed and the resulting values were divided into classes again. The result of this analysis is shown in Annex T.6.

### 7. Answer to question: Is the species richness in the subzone high?

To answer this question the whole species list was used (rare species and regularly occurring species). The average number of species per grid cell was calculated by first determining the number of species per sample, than average them per station and then per grid cell (similar to the method for “Is the subzone characterized by many rare species” described above). Five species richness classes were created based on the range of these values. The result of this analysis is shown in Annex T.7.

### 8. Answer to question: Are there distinctive/unique communities present in the subzone?

Through the methodology explained in chapter IV it was possible to predict which macrobenthic communities have the highest probability to occur in a grid cell. Four communities were considered for this purpose: the *Abra alba* community, the *Macoma balthica* community, the *Nepthys cirrosa* community and the *Ophelia limacina* community. Other species associations occur on the BPNS but these are all transitions between these four communities. This prediction allows creating full-coverage maps showing the distribution of the habitat suitability of the different communities. The sample data which are available for 725 grid cells could then be coupled to this community information and this made it possible to calculate the average species richness and density for each community ($SPR_{Abra}$, $SPR_{Macoma}$, $DENS_{Abra}$, $DENS_{Nepthys}$,….). Then the average species richness and average density of the whole BPNS is determined ($SPR_{avg}$, $DENS_{avg}$). When the average species richness (/density) of a community is divided by the average species richness (/density) of the BPNS the following ratios are obtained $SPR_{Abra}/SPR_{avg}$, $SPR_{Macoma}/SPR_{avg}$, $SPR_{Nepthys}/SPR_{avg}$, $SPR_{Ophelia}/SPR_{avg}$, $DENS_{Abra}/DENS_{avg}$, $DENS_{Macoma}/DENS_{avg}$, $DENS_{Nepthys}/DENS_{avg}$, $DENS_{Ophelia}/DENS_{avg}$, $SPR_{Abra}/SPR_{avg}$ (Table 11). A word of caution regarding the high SPR and DENS ratios of the *Abra alba* community has to be put here since this community has been intensively sampled during recent years which will certainly have contributed to the higher species richness and densities found for this community. Multiplying the SPR ratio with the DENS ratio for each community gives a unique value for each community, reflecting its corresponding value (in terms of species richness and density). Based on the range of these values 5 classes (1 to 5) are determined and each community is linked to a class (*Abra alba* community: 5, very high value – *Nephtys cirrosa* community: 3, medium value – *Macoma balthica* community: 2, low value – *Ophelia limacina* community: 1, very low value). These class values are then assigned to each grid cell where the corresponding community is predicted. This gives a full-coverage valuation map. The result of this analysis is shown in Annex T.8.

**Table 11: SPR and DENS ratio of every community of the BPNS.**

| Community | SPR ratio | DENS ratio | SPR ratio x DENS ratio |
|---|---|---|---|
| *Abra alba* community | 1,03111638 | 1,20774017 | 1.24532 |
| *Macoma balthica* community | 0,47460922 | 1,03410404 | 0.49080 |
| *Nephtys cirrosa* community | 0,89115026 | 0,78017409 | 0.69525 |
| *Ophelia limacina* community | 0,60356201 | 0,35747274 | 0.21577 |

## *D. Marine biological valuation map of macrobenthos of the BPNS*

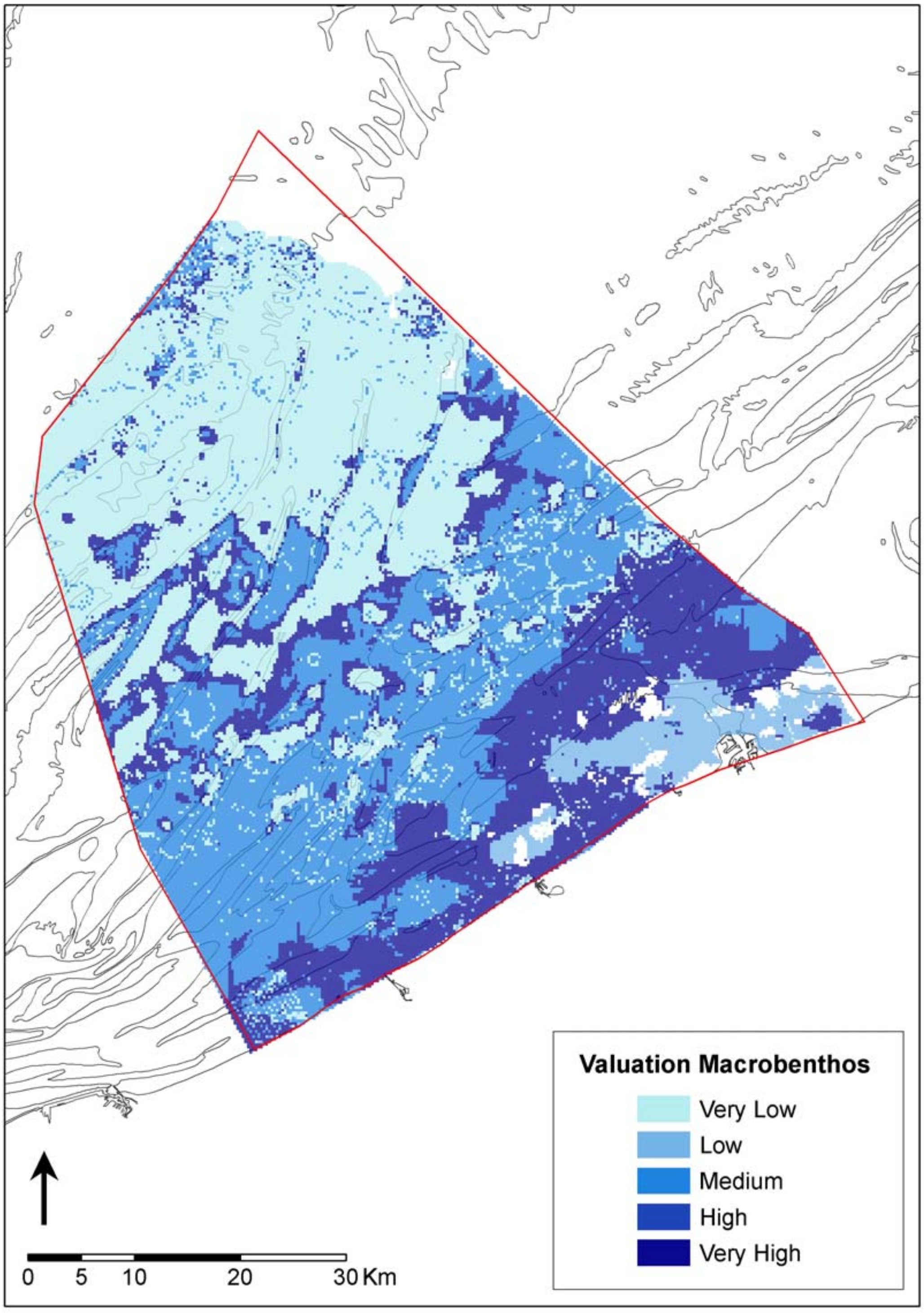


**Figure 7: Marine biological valuation map of macrobenthos of the BPNS.**

## *E.* *RELIABILITY OF RESULTS*

The sampling method was the same for all macrobenthic samples taken from 1994 onwards, so there is no difference in reliability based on sampling method for the different samples. The reliability of the macrobenthos valuation map was determined by analysing the number of samples in each grid (sampling effort).

Grids where no information was available (even no information on the predicted communities) were labelled ‘no data’. Grids where the only information resulted from the habitat suitability prediction of the macrobenthic communities (see question 8 above) were given a ‘low’ reliability label as the valuation of these grids is only determined through modelling (because of the lack of ground truthing data). For the other grids, where point data from sampling were available, a reliability classification (for ‘medium’ and ‘high’ reliability) was made by analysing the number of stations per grids, the number of samples for these stations and the number of replicates taken in each of these samples. By summing up these values for each grid cell a range was determined which allows division into the reliability classes “medium” and “high”.

The map showing the reliability of the results for macrobenthos is shown in Annex U.

## *F.* *DISCUSSION OF MAPS*

The highest biological value for macrobenthos was found in the coastal zone, especially near shore in the western coastal area and diverging to the Akkaert bank in the eastern coastal area. Other valuable areas for macrobenthos seem to be the gully above the Thornton Bank and an area between the Vlaamse and the Hinder banks. The lowest biological values were found offshore and in the coastal area around Zeebrugge and the mouth of the Westerschelde. The areas of the Vlaamse banks and the Zeeland banks had a medium value. It has to be emphasized that this biological valuation map for macrobenthos is strongly biased by the output of the community question (question 8 above) as this is the only question which could be answered for a lot of grid cells. Where the total biological value, for macrobenthos, in a grid cell is based on more than one question this value will be more reliable as this value integrates both predicted community information and information from samples.

Annex T.1 shows that the highest counts of macrobenthic species were found in the western coastal area, especially in the swales Potje and Westdiep. The Trapegeer sandbank has a rather low value. Intermediate to high counts of macrobenthic species were found on the slopes of the Midddelkerke bank. The middle and east coast show low values, as does the area of the Hinder banks and the offshore region. Intermediate values are also found east of the Zeeland banks.

A similar pattern is seen in Annex T.2, which shows the areas where one or more macrobenthic species tend to aggregate. However, slightly higher values were found in the area north of the Hinder banks.

The areas where many rare species are found are shown in Annex T.3. This map shows only a slight peak in the distribution of rare macrobenthic species in the Westdiep swale. Most other areas of the BNPS have intermediate values for this question.

The abundance of rare species (Annex T.4) was mostly low to medium in the coastal area. High values were found on the slopes of the Middelkerke bank. Some spots of high value were also found in the vicinity of the Fairy bank and the Bligh bank.

As seen in Annex T.5, the highest densities of the tube building polychaet *Lanice conchilega* were found in the western coastal area (Potje and Westdiep swales), around the Middelkerke bank and east of the Akkaert bank. Low densities were found on the tops of most sandbanks, in the gullies around the Oostdyck and Buiten Ratel banks and in the east coast region.

Annex T.6 shows the combined density of macrobenthos species *Abra alba* and *Spisula subtruncata.* High densities of these species were seen in the western coastal area, especially in the Westdiep swale, while intermediate densities were seen in the rest of this area (Potje, Trapegeer bank). The area of the Hinder banks and above the Zeeland banks shows low values for this question, while intermediate values were found for the east coast, above the Vlakte van de Raan and around the Middelkerke bank.

The macrobenthic species richness (Annex T.7) was high in the western coastal swales (Potje and Westdiep), on the slopes of the Middelkerke bank and east of the Akkaert bank. Low species richness was found on the tops of most sandbanks and in the eastern coastal zone. Intermediate values for species richness were found in the offshore zone and around the western part of the Vlaamse banks and around the Hinder banks.

As can be seen on the map of Annex T.8 the values of the predicted macrobenthic communities correspond largely with the total macrobenthic valuation map, as this is the only information available for the majority of the grid cells. The highly valuable *Abra alba* community seemed to occur mostly in the coastal area, ranging from very nearshore in the western part to approximately 15 km offshore in the eastern part. The community was also found around the southern part of the Hinder banks and the northern part of the Zeeland banks. The *Macoma balthica* community, with a low biological value as determined in this study, occurred mainly in the eastern coastal zone and around the harbour of Oostende. The offshore areas were mostly inhabited by the *Ophelia limacina* community, having a very low biological value. The medium valuable *Nephtys cirrosa* community is mainly restricted to the Vlaamse and Zeeland banks.

# VII. Marine biological valuation of epibenthos of the BPNS

Ine Moulaert, Pieter Deckers, Klaas Deneudt & Kris Hostens

## *A. INTRODUCTION*

ILVO-Fisheries has been gathering data on the epibenthos since the late 1970's, mainly to investigate the influence of different anthropogenic activities like dredge dumping, sand extraction and the construction of pipelines and windmill farms. However one of the main shortcomings in the valuation of the epibenthos is that most long-term data have been gathered in the gullies. Only during the recent years some data on the presence of the epibenthos are available for the sandbanks. As such only part of the whole BPNS has been covered so far. Also, a clear relation between the presence or abundance of the epibenthic organisms and the environment has not yet been established, which makes it impossible to make extrapolations to the surrounding areas. Therefore the valuation maps for the epibenthos will be limited to those grid cells that are covered by one or more sampling tracks.

## *B. DATA COLLECTION*

The epibenthos was sampled twice a year (spring and autumn) with a so-called shrimptrawl, equipped with an 8 meters beam trawl, a fine meshed net (22 mm) and a boll-chain in the groundrope. The duration of each trawl was 30 minutes with an average speed of 3.5 knots. This way an average distance of 3500 m was trawled. Per trawl the main community characteristics (species richness, density and biomass) were calculated. Density and biomass (wet weight) were standardised to an area of 1000 m², based on the trawled distance and the width of the beam trawl. The epibenthos was divided in three fractions: a coarse fraction (including fish and 'large' epibenthos), a shrimp fraction (mainly crustaceans, small fish and echinoderms) and a fine fraction (mainly small molluscs and debris). If a sample was too large, sub-samples of each fraction were taken. All individuals were identified up to species level whenever possible, counted and weighted (wet weight). Non-epibenthic species, that were only sporadically caught in the net (e.g. polychaetes), were eliminated from the dataset. The final dataset is based on data from both spring (February-April) and autumn (September-October) campaigns from 1993 to 2005. Although data have been gathered before that period, the data set was limited to this period for comparative reasons.

## *C. APPLICATION OF VALUATION CRITERIA ON THE EPIBENTHOS DATA*

A grid of 250 x 250 m was used for the epibenthos (cf. the macrobenthos) to superimpose the trawl data. The grid coordinates were taken from an ArcView layer provided by VLIZ. All grid cells that were covered by a track got the value of that track both for the density and species richness data. The conversion from trawls to grid was done by VLIZ. When more than one track passed over a grid cell (because over all these years and seasons the same track has been sampled several times), this cell got the average of the tracks, based on the criteria specified below.

Whenever a grid cell had no tracks passing through, the flag “N/A” was given to that cell. On the other hand when a species was not found in a track, the cell got the value "0" for that species. For the calculation of the different algorithms, except for the species richness (question 4), only the regularly occurring species were used in the valuation process. This means that only those species that occurred in more than 5% of the tracks (> 21 tracks) were used. This resulted in a list of 38 epibenthic species. For each of these regularly occurring species only the data from one season were used. In order to determine the most relevant season per species, the average density per season was calculated for each species by dividing the sum off all densities per species with the total number of trawls per season (see Table 12). The season with the highest average density for every single species was kept for further analyses.

For the epibenthos, only five questions could be answered, as not enough information was available to answer the other questions. All data were stored in an MS-Access database. The questions were solved through queries and formulas in MS Access and MS Excel.

Is the subzone characterized by high counts of many species?
Is the abundance of a certain species very high in the subzone?
Is the abundance of ecologically significant species high in the subzone?
Is the species richness in the subzone high?
Is the subzone highly productive?

**Table 12: List of the epibenthic species present in more than 5% of the sampling tracks. In the right column the season with the highest average density per species is indicated.**

| SPECIES | SEASON |
|---|---|
| *Abra alba* | autumn |
| *Alloteuthis subulata* | autumn |
| *Anthozoa spp.* | spring |
| *Aphrodita aculeata* | autumn |
| *Asterias rubens* | autumn |
| *Buccinum undatum* | autumn |
| *Carcinus maenas* | autumn |
| *Crangon allmanni* | autumn |
| *Crangon crangon* | autumn |
| *Crepidula fornicata* | spring |
| *Donax vittatus* | autumn |
| *Echinocardium cordatum* | spring |
| *Ensis directus* | autumn |
| *Liocarcinus depurator* | autumn |
| *Liocarcinus arcuatus* | autumn |
| *Liocarcinus holsatus* | autumn |
| *Liocarcinus marmoreus* | autumn |
| *Loligo vulgaris* | autumn |
| *Macoma balthica* | spring |
| *Macropodia rostrata* | autumn |
| *Mactra stultorum* | autumn |
| *Mytilus edulis* | autumn |
| *Nassarius reticulatus* | spring |
| *Necora puber* | autumn |
| *Ophiura albida* | spring |
| *Ophiura ophiura* | autumn |
| *Pagurus bernhardus* | autumn |
| *Palaemon serratus* | autumn |
| *Pandalus montagui* | autumn |
| *Pectinaria koreni* | autumn |
| *Pontophilus trispinosus* | autumn |
| *Psammechinus miliaris* | spring |
| *Sepia officinalis* | autumn |
| *Sepiola atlantica* | autumn |
| *Spisula elliptica* | autumn |
| *Spisula solida* | autumn |
| *Spisula subtruncata* | autumn |
| *Thia scutellata* | spring |

### 1. Answer to question: Is a subzone characterized by high counts of many species

To answer this question the average density over the period 1993-2005 was calculated per grid cell for every regularly occurring species, based on the most relevant season per species. Two tables were created: a first one to calculate the sum of densities per grid per species and a second in which the number of trawls per grid per season was calculated. Next a cross-table was created in which the average density per grid cell and per species was calculated by dividing the sum of density by the number of trawls per grid cell. Per species, the average density was then divided into 5 classes. All these values were summed and divided by the number of species that were used: 8 species when only a spring track runs through the grid, 30 for autumn and 38 when both spring and autumn tracks were used. This final result was then again divided into five classes with a more or less equal amount of grid cells in each class. The result of this analysis is shown in Annex W.1.

### 2. Answer to question: Is the abundance of a certain species very high in the subzone?

The high abundance of certain species is a combination of the density of a number of species and the level of aggregation of those species.

Again based on the most relevant season per species, the average density over the period 1993-2005 and over the whole study area (=X) was calculated for every regularly occurring species. Therefore, the sum of all densities per species was divided by the total number of trawls sampled in the relevant season associated with that species. The average density of every species for every grid cell (=Xi) was calculated like in question 2. In MS-Excel the ratio Xi/X for each species in every grid cell was calculated.

Per species the top 5% cells with the highest ratio were determined (for species with autumn as the relevant season, 108 cells made up the 5% top cells; for species with spring as the relevant season the top 73 cells had to be taken into account). The percentage of the average density present in these top 5% cells compared to the total summed average density over all cells was calculated for every species (=Y). The aggregation coefficient (Y/Z) was calculated for each species by dividing the value Y by the number of grid cells in which that species occurred (=Z). (Table 13)

The ratio values (Xi/X) per species were divided into five classes. These classes were then multiplied with the species specific aggregation coefficients (Y/Z). Per grid cell the results for all species were summed and divided by 8, 30 or 38, depending on the season(s) used. For the final result these values were again divided into five equal classes. The result of this analysis is shown in Annex W.2.

**Table 13: Calculated values of Y (5%), Z and Y/Z (i.e. the aggregation coefficient) for the regularly occurring epibenthos species.**

| SPECIES | Y | Z | Y/Z |
|---|---|---|---|
| *Abra alba* | 99.6 | 548 | 0.18 |
| *Alloteuthis subulata* | 31.4 | 1553 | 0.02 |
| *Anthozoa spp.* | 63.7 | 906 | 0.07 |
| *Aphrodita aculeata* | 95.6 | 243 | 0.39 |
| *Asterias rubens* | 48.7 | 1946 | 0.03 |
| *Buccinum undatum* | 99.6 | 153 | 0.65 |
| *Carcinus maenas* | 90.3 | 252 | 0.36 |
| *Crangon allmanni* | 54.0 | 1161 | 0.05 |
| *Crangon crangon* | 37.2 | 1891 | 0.02 |
| *Crepidula fornicata* | 96.9 | 354 | 0.27 |
| *Donax vittatus* | 98.7 | 474 | 0.21 |
| *Echinocardium cordatum* | 97.7 | 349 | 0.28 |
| *Ensis directus* | 67.3 | 765 | 0.09 |
| *Liocarcinus depurator* | 95.3 | 393 | 0.24 |
| *Liocarcinus arcuatus* | 65.5 | 732 | 0.09 |
| *Liocarcinus holsatus* | 33.2 | 2142 | 0.02 |
| *Liocarcinus marmoreus* | 56.2 | 1052 | 0.05 |
| *Loligo vulgaris* | 45.0 | 1061 | 0.04 |
| *Macoma balthica* | 95.8 | 333 | 0.29 |
| *Macropodia rostrata* | 54.6 | 1109 | 0.05 |
| *Mactra stultorum* | 96.8 | 250 | 0.39 |
| *Mytilus edulis* | 96.4 | 228 | 0.42 |
| *Nassarius reticulatus* | 94.2 | 605 | 0.16 |
| *Necora puber* | 75.1 | 454 | 0.17 |
| *Ophiura albida* | 69.7 | 1269 | 0.05 |
| *Ophiura ophiura* | 73.5 | 2046 | 0.04 |
| *Pagurus bernhardus* | 45.3 | 2008 | 0.02 |
| *Palaemon serratus* | 99.95 | 112 | 0.89 |
| *Pandalus montagui* | 84.9 | 300 | 0.28 |
| *Pectinaria koreni* | 98.1 | 388 | 0.25 |
| *Pontophilus trispinosus* | 58.6 | 574 | 0.10 |
| *Psammechinus miliaris* | 53.7 | 775 | 0.07 |
| *Sepia officinalis* | 73.3 | 661 | 0.11 |
| *Sepiola atlantica* | 42.1 | 1232 | 0.03 |
| *Spisula elliptica* | 69.8 | 627 | 0.11 |
| *Spisula solida* | 45.3 | 839 | 0.05 |
| *Spisula subtruncata* | 95.0 | 605 | 0.16 |
| *Thia scutellata* | 65.1 | 322 | 0.20 |

### 3. Answer to question: Is the abundance of certain ecologically significant species high in the subzone?

Brown shrimp *Crangon crangon* is the most abundant epibenthic crustacean in most coastal marine environments. It is an important food source for gadoids, pleuronectids and gobies and several seabird species, like gulls and terns (http://www.marlin.ac.uk). Therefore, *Crangon crangon* can be seen as an ecological significant species.

For every grid cell the average density was calculated by dividing the total density in the most relevant season over the period 1993-2005 per cell with the number of autumn trawls running over that cell. A table was created with grid cell species (set to *Crangon crangon*), season (set to autumn), sum of density and number of trawls per grid. In a second table, the sum of density was divided by the number of trawls per grid. These results were then put into five classes, where the class 1 contained all zero values and the other values were equally divided over classes 2 to 5. The result of this analysis is shown in Annex W.3.

### 4. Answer to question: Is the species richness in the subzone high?

For this algorithm the whole dataset was used (all species, all seasons). The map showing the species richness was developed using the average number of species found per grid cell. As such some information was lost on the real species richness. However, when using the total or maximum number of different species found, the results were biased by the sampling effort, the number of trawls per grid (see Annex V).

In MS Access a table was created with grid cell, trawl identifier and the count of species. This temporary table was then used to calculate the average number of species found per grid cell. These values per cell were then divided in five species richness classes with a more or less equal amount of grid cells within each class. The result of this analysis is shown in Annex W.4.

### 5. Answer to question: Is the subzone highly productive?

For this question wet weight biomass was used as a proxy for productivity. It is known that for most epibenthic species the productivity is related to biomass by means of a P/B ratio 2.5.

The average biomass over the period 1993-2005 was calculated per grid cell for every regularly occurring species, again based on the most relevant season per species (cf. question 1). The total average epibenthic biomass per grid cell was then calculated by summing all average biomasses and dividing this with 8, 30 or 38 depending on the season(s) used.. These results were divided into five equally sized classes. The result of this analysis is shown in Annex W.5.

## *D. MARINE BIOLOGICAL VALUATION MAP OF EPIBENTHOS OF THE BPNS*

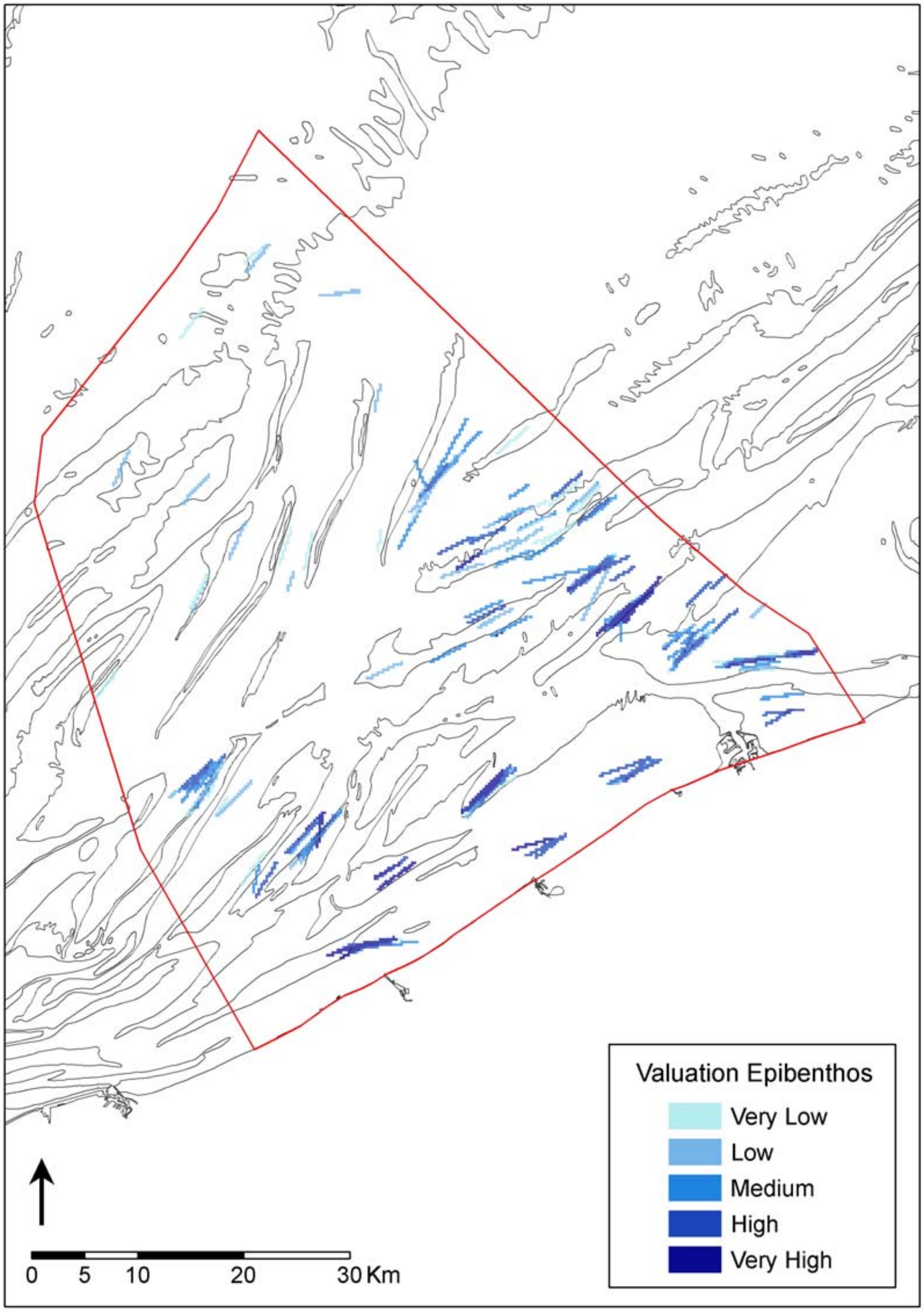


**Figure 8: Marine biological valuation map of epibenthos of the BPNS.**

## *E.* RELIABILITY OF RESULTS

Sampling methodology (8-m beam trawl, shrimp net, distance and trawling speed, sample processing, etc.) has been uniform for all trawls in the period 1993-2005. Therefore, the reliability of all data is the same. The main bias is generated by sampling effort. The reliability of the value that is given to a certain grid cell is higher when more tracks are passing through that cell. The cells that only have 1 track passing through received the reliability label 'low', cells between 2 and 5 tracks 'medium' and all grid cells with more then 5 tracks 'high'.

On the other hand species richness might be biased due to the more detailed identification of several epibenthic taxa in recent years, which sometimes were lumped at a higher taxon level in previous years. Another problem is the fact that the average values for several species may be overestimated due to one or more high 'recruitment' peaks throughout the whole period. Also, as explained in the introduction, an extrapolation from the track/grid cells to the rest of the BPNS was impossible. The map showing the reliability of the results for epibenthos is shown in Annex X.

## *F.* DISCUSSION OF THE MAPS

The ultimate valuation map shows that the coastal area has the highest biological value for the epibenthos. The Vlaamse and Zeeland banks have an intermediate to high value, whereas the offshore areas have a low to very low biological value based on epibenthos data.

Annex W.1 shows that the highest counts of epibenthic species were found in the zone running from the western coastal zone to a zone more offshore in the eastern part of the BPNS, including the Vlaamse and Zeeland banks. Also the western area of the Hinderbanks showed some high to very high values. The lowest epibenthic densities were clearly found in the eastern coastal zone, up to 15-20 km out of the coast, between the mouth of the Westerschelde and the harbor of Oostende and also in the most offshore regions of the BPNS.

The map in Annex W.2 clearly indicates areas where one or more species tend to aggregate. High scores were noted for the coastal zone and the gullies in the sandbank complex of the Vlaamse and Zeeland banks, while low to medium scores were noted on top of these sandbanks and in the offshore zone.

The ecological significant epibenthic species *Crangon crangon* (Annex W.3) was only present in high densities in the coastal area, with the highest densities found in the eastern coastal zone. Densities were low 15-30 km out of the coast, and *Crangon crangon* was absent in the offshore zones of the BPNS.

As was expected, the highest epibenthic species richness (Annex W.4) was found in the zone running from the western coastal zone to a zone more offshore in the eastern part of the BPNS, including the gullies of the Vlaamse banks and the Zeeland banks. Also some of the grid cells in the offshore area showed a high species richness. The eastern coastal area, near the mouth of the Westerschelde estuary and the harbour of Zeebrugge, clearly had a lower species richness.

The coastal zone clearly showed the highest epibenthic productivity, as shown in Annex W.5. Although the densities measured in the eastern coastal area of the BPNS were lower, the scores for biomass in this area were comparable to the western coastal zone. Low to medium scores for productivity were found for the area 20-30 km out of the coast. The further offshore area only had low biomass values.

# VIII. Marine biological valuation of demersal fish of the BPNS

Ine Moulaert, Pieter Deckers, Klaas Deneudt & Kris Hostens

## A. INTRODUCTION

ILVO-Fisheries has been gathering data on the demersal fish since the late 1970's, mainly to investigate the influence of different anthropogenic activities like dredge dumping, sand extraction and the construction of pipelines and windmill farms. However one of the main shortcomings in the valuation of the demersal fish is that most long-term data have been gathered in the gullies.Only during the recent years some data on the presence of the demersal fish are available for the sandbanks. As such only part of the whole BPNS has been covered so far. Also, a clear relation between the presence or abundance of the demersal fish and the environment has not yet been established, which makes it impossible to make extrapolations to the surrounding areas. Therefore the valuation maps for the demersal fish will be limited to those grid cells that are covered by one or more sampling tracks.

## B. DATA COLLECTION

The demersal fish was sampled twice a year (spring and autumn) with a so-called shrimp trawl, equipped with an 8 meters beam trawl, a fine meshed net (22 mm) and a roll-chain in the ground rope. The duration of each trawl was 30 minutes with an average speed of 3.5 knots. This way an average distance of 3500 m was trawled. Per trawl the main community characteristics (species richness and density) were calculated. Density was standardized to an area of 1000 m², based on the trawled distance and the width of the beam trawl. All individuals were identified up to species level and counted. The final dataset is based on data from both spring (February-April) and autumn (September-October) campaigns from 1996 to 2005. Although data have been gathered before that period, the data set was limited to this period for comparative reasons.

## C. APPLICATION OF VALUATION CRITERIA ON DEMERSAL FISH DATA

A grid of 250 x 250 m was used for the demersal fish (cf. the epibenthos) to superimpose the trawl data. The grid coordinates were taken from an ArcView layer provided by VLIZ. All grid cells that were covered by a track got the value of that track both for the density and species richness data. The conversion from trawls to grid was done by VLIZ. When more than one track passed over a grid cell (because over all these years and seasons the same track has been sampled several times), this cell got the average of the tracks, based on the criteria specified below.

Whenever a grid cell had no tracks passing through, the flag “N/A” was given to that cell. On the other hand when a species was not found in a track, the cell got the value "0" for that species. For the calculation of the different algorithms, except for the species richness (question 3), only the regularly occurring species were used in the valuation process. This means that only those species that occurred in more than 5% of the tracks (> 21 tracks) were used. This resulted in a list of 27 demersal fish species. For each of these regularly occurring species only the data from one season were used. In order to determine the most relevant season per species, the average density per season was calculated for each species by dividing the sum off all densities per species with the total number of trawls per season. The season with the highest average density for every single species was kept for further analyses (see Table 14).

For the demersal fish, only three questions could be answered, as not enough information was available to answer the other questions. No ecological significant species were chosen for question 4. Although gobies and the lesser sand-eel are important food sources for higher organisms, the sampling gear (20-mm meshed net) is not sufficiently adapted for the efficient catch of these species. All data were stored in an MS-Access database. The questions were solved through queries and formulas in MS Access and MS Excel.

Is the subzone characterized by high counts of many species?
Is the abundance of a certain species very high in the subzone?
Is the species richness in the subzone high?

**Table 14: List of the demersal fish species present in more than 5% of the sampling tracks. In the right column the season with the highest average density per species is indicated.**

| SPECIES | SEASON |
|---|---|
| *Agonus cataphractus* | autumn |
| *Ammodytes tobianus* | autumn |
| *Arnoglossus laterna* | autumn |
| *Buglossidium luteum* | autumn |
| *Callionymus lyra* | autumn |
| *Callionymus reticulatus* | autumn |
| *Ciliata mustela* | autumn |
| *Clupea harengus* | spring |
| *Echiichtys vipera* | autumn |
| *Eutrigla gurnardus* | autumn |
| *Gadus morhua* | spring |
| *Hyperoplus lanceolatus* | autumn |
| *Limanda limanda* | autumn |
| *Liparis liparis* | autumn |
| *Merlangus merlangus* | spring |
| *Microstomus kitt* | autumn |
| *Mullus surmuletus* | autumn |
| *Myoxocephalus scorpius* | spring |
| *Platichtys flesus* | spring |
| *Pleuronectes platessa* | autumn |
| *Pomatoschistus spp.* | autumn |
| *Solea solea* | autumn |
| *Sprattus sprattus* | spring |
| *Syngnathus acus* | spring |
| *Trachurus trachurus* | autumn |
| *Trigla lucerna* | autumn |
| *Trisopterus spp.* | autumn |

### 1. Answer to question: Is the subzone characterised by high counts of many species?

To answer this question the average density over the period 1996-2005 was calculated per grid cell for every regularly occurring species, based on the most relevant season per species. Two tables were created: a first one to calculate the sum of densities per grid per species and a second in which the number of trawls per grid per season was calculated. Next a cross-table was created in which the average density per grid cell and per species was calculated by dividing the sum of density by the number of trawls per grid cell. Per species, the average density was then divided into five classes. All these values were summed and divided by the number of species that were used: 7 species when only a spring track runs through the grid, 20 for autumn and 27 when both spring and autumn tracks were used. This final result was then again divided into five classes with a more or less equal amount of grid cells in each class. The result of this analysis is shown in Annex Z.1.

### 2. Answer to question: Is the abundance of a certain species very high in the subzone?

The high abundance of certain species is a combination of the density of a number of species and the level of aggregation of those species.

Again based on the most relevant season per species, the average density over the period 1996-2005 and over the whole study area (=X) was calculated for every regularly occurring species. Therefore, the sum of all densities per species was divided by the total number of trawls sampled in the relevant season associated with that species. The average density of every species for every grid cell (=Xi) was calculated like in question 2. In MS-Excel the ratio Xi/X for each species in every grid cell was calculated.

Per species the top 5% cells with the highest ratio were determined (for species with autumn as the relevant season, 108 cells made up the 5% top cells; for species with spring as the relevant season the top 73 cells had to be taken into account). The percentage of the average density present in these top 5% cells compared to the total summed average density over all cells was calculated for every species (=Y). The aggregation coefficient (Y/Z) was calculated for each species by dividing the value Y by the number of grid cells in which that species occured (=Z). (see Table 15).

The ratio values (Xi/X) per species were divided into five classes. These classes were then multiplied with the species specific aggregation coefficients (Y/Z). Per grid cell the results for all species were summed to get one total value. For the final result these values were again divided into 5 equal classes. The result of this analysis is shown in Annex Z.2.

**Table 15: Calculated values for Y (5%), Z and Y/Z for the frequently occurring demersal fish species**.

| SPECIES | Y | Z | Y/Z |
|---|---|---|---|
| *Agonus cataphractus* | 53.9 | 1532 | 0.04 |
| *Ammodytes tobianus* | 50.8 | 1138 | 0.04 |
| *Arnoglossus laterna* | 41.6 | 1231 | 0.03 |
| *Buglossidium luteum* | 47.9 | 1484 | 0.03 |
| *Callionymus lyra* | 33.0 | 1741 | 0.02 |
| *Callionymus reticulatus* | 45.3 | 1270 | 0.04 |
| *Ciliata mustela* | 68.4 | 460 | 0.15 |
| *Clupea harengus* | 45.9 | 1202 | 0.04 |
| *Echiichtys vipera* | 30.4 | 1244 | 0.02 |
| *Eutrigla gurnardus* | 46.6 | 1107 | 0.04 |
| *Gadus morhua* | 64.5 | 915 | 0.07 |
| *Hyperoplus lanceolatus* | 35.8 | 874 | 0.04 |
| *Limanda limanda* | 57.6 | 1936 | 0.03 |
| *Liparis liparis* | 83.9 | 515 | 0.16 |
| *Merlangus merlangus* | 58.1 | 1334 | 0.04 |
| *Microstomus kitt* | 82.6 | 313 | 0.26 |
| *Mullus surmuletus* | 46.4 | 873 | 0.05 |
| *Myoxocephalus scorpius* | 42.7 | 487 | 0.09 |
| *Platichtys flesus* | 45.5 | 841 | 0.05 |
| *Pleuronectes platessa* | 49.8 | 1946 | 0.03 |
| *Pomatoschistus spp.* | 53.5 | 1912 | 0.03 |
| *Solea solea* | 50.2 | 1516 | 0.03 |
| *Sprattus sprattus* | 45.1 | 1227 | 0.04 |
| *Syngnathus acus* | 72.1 | 264 | 0.27 |
| *Trachurus trachurus* | 65.2 | 1250 | 0.05 |
| *Trigla lucerna* | 50.2 | 451 | 0.11 |
| *Trisopterus spp.* | 23.8 | 1689 | 0.01 |

## 3. Answer to question: Is the species richness in the subzone high?

For this algorithm the whole dataset was used (all species, all seasons). The map showing the species richness was developed using the average number of species found per grid cell. As such, some information was lost on the real species richness. However, when using the total or maximum number of different species found, the results were biased by the sampling effort, i.e. the number of trawls per grid (see Annex Y).

In MS Access a table was created with grid cell, trawl identifier and the count of species. This temporary table was then used to calculate the average number of species found per grid cell. These values per cell were then divided in five species richness classes with a more or less equal amount of grid cells within each class. The result of this analysis is shown in Annex Z.3.

## *D. MARINE BIOLOGICAL VALUATION MAP OF THE DEMERSAL FISH OF THE BPNS*

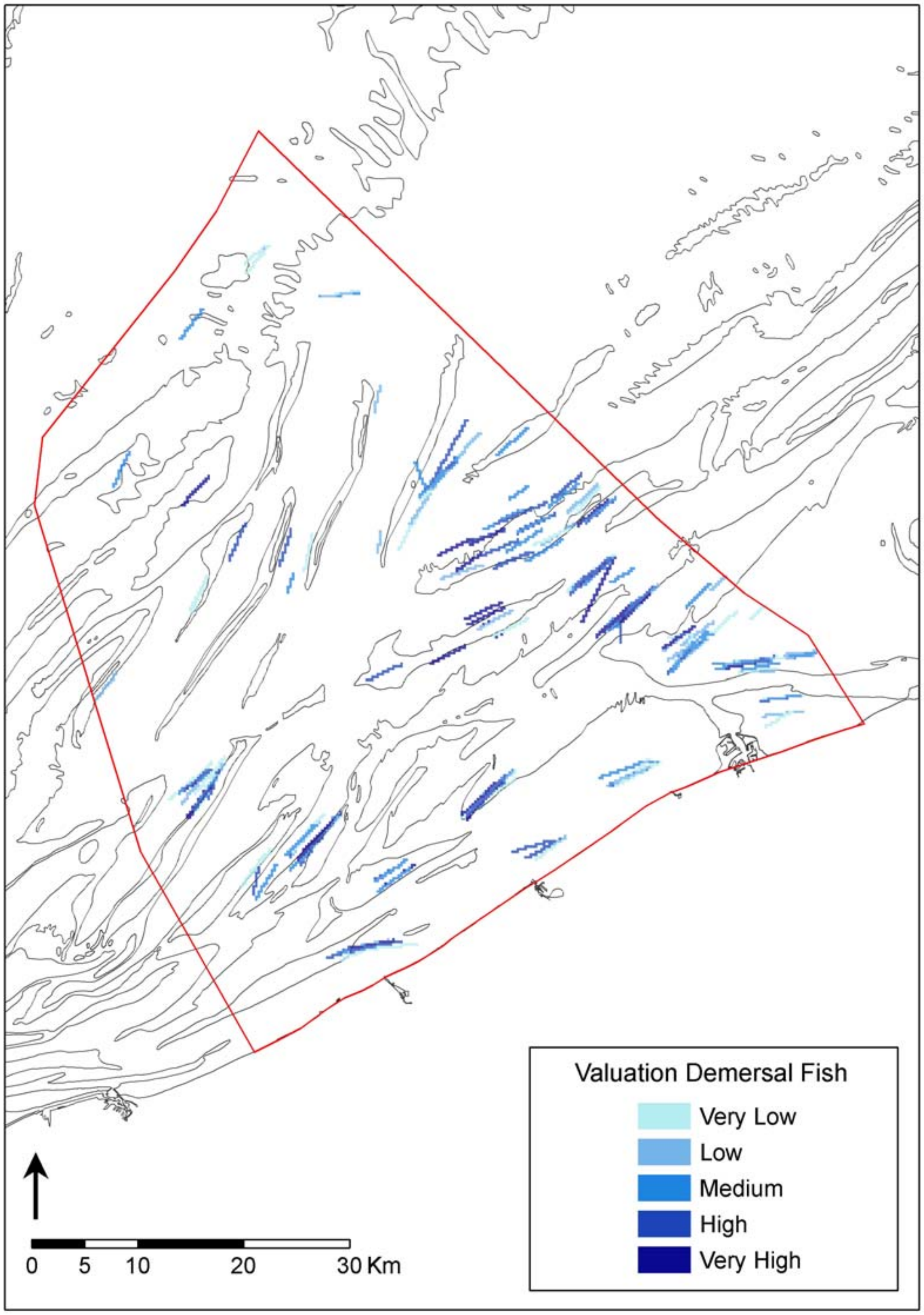


**Figure 9: Marine biological valuation map of demersal fish of the BPNS.**

## *E. RELIABILITY OF RESULTS*

Sampling methodology (8-m beam trawl, shrimp net, distance and trawling speed, sample processing, etc.) has been uniform for all trawls in the period 1996-2005. Therefore, the reliability of all data is the same. The main bias is generated by sampling effort. The reliability of the value that is given to a certain grid cell is higher when more tracks are passing through that cell. The cells that only have 1 track passing through received the reliability label 'low', cells between 2 and 5 tracks 'medium' and all grid cells with more then 5 tracks 'high'. This clearly indicates that the coastal area has a medium to high reliability, whereas the offshore region only has a low reliability.

On the other hand species richness might be biased due to the more detailed identification of several taxa in recent years, which sometimes were lumped at a higher taxon level in previous years. Another problem is the fact that the average values for several species may be overestimated due to one or more high 'recruitment' peaks throughout the whole period. Also, as explained in the introduction, an extrapolation from the track/grid cells to the rest of the BPNS was impossible.

The map showing the reliability of the results for demersal fish is shown in Annex AA.

## *F. DISCUSSION OF MAPS*

Areas with a high to very high biological value are found all over the BPNS. Lowest values are calculated for the offshore deeper areas and the eastern coastal zone between Oostende and the mouth of the Westerschelde.

The map of Annex Z.1 shows that high densities of demersal fish were found all over the BPNS with the exception of the coastal zone between the harbor of Oostende and the mouth of the Westerschelde and the most offshore zone.

Annex Z.2 indicates areas that are characterized by high densities in association with the presence of species that are aggregated in this area. Highest scores were found in the coastal area (< 25 km). Species with the highest aggregation coefficients were recorded in the eastern coastal area: the greater pipefish *Syngnathus acus,* Fivebeard rockling *Ciliata mustela* and the sea snail *Liparis liparis.* Intermediate scores were calculated for the Zeeland banks. For the offshore area low to intermediate scores were found.

The highest species richness was found on the slopes of the Vlaamse and Zeeland banks and in the western offshore area of the BPNS, as shown in Annex Z.3. The western coastal zone had low to intermediate values, whereas the eastern coastal zone had mostly low values.

# IX. The marine biological valuation map of the BPNS

Sofie Derous, Wouter Courtens, Pieter Deckers, Klaas Deneudt, Eric Stienen, Vera Van Lancker, Els Verfaillie, Magda Vincx & Steven Degraer

Figure 10 below shows the marine biological valuation map of the BPNS, integrating the valuation of the seabirds, macro- en epibenthos en demersal fish. The methodology used to develop this map is explained in Chapters II to VIII. The protocol for marine biological valuation was built around the valuation criteria selected in Chapter II. For each ecosystem component the most relevant assessment questions, given in the protocol of Chapter III, were selected based on the data availability. These assessment questions were translated into mathematical algorithms which could be used to query the database. These algorithms are explained in the Chapters V-VIII. To be able to develop full-coverage maps for seabirds and macrobenthos some extrapolation techniques were applied to the available data. The extrapolation technique for macrobenthos was combined with a predictive model which is explained in Chapter IV. The extrapolation technique for seabirds is explained in Chapter V (data analysis).

The total biological value of a grid cell was determined by averaging the values for the different ecosystem components. When no values were available for a certain ecosystem component (e.g. epibenthos, demersal fish,…) then the total biological value was determined by only taking into account the values that were available for the other ecosystem components. Other scoring systems could be applied to the database but as this would only confound the results, these alternative scenarios are not integrated in the report. These scoring alternatives will be explored in the future to see how they influence the valuation results.

This map shows that the most valuable areas can be found in the coastal area of the BPNS, with high to very high values found for the entire coastal strip, stretching out to the Oostende sandbank in the west and to the Akkaert bank in the east.

High values are also found in the area around the Thornton bank and in the area south of the Hinder banks.

Intermediate values are found in the area of the Vlaamse and Hinder banks.

The offshore area of the BPNS is almost always characterized by a low biological value.

The reliability of the values shown on the total biological valuation map is indicated on Figure 11: Reliability of the total biological valuation map. This reliability score integrates the reliability scores (ranging from 1 to 3) of the valuation maps for each of the ecosystem components (seabirds, macro- and epibenthos and demersal fish), and thus reflects the sampling/observation intensity of the BPNS. When no value for epibenthos or demersal fish could be determined (due to the lack of data, i.e. white areas on these valuation maps), a reliability score of 0 was taken for the integration of the separate reliability scores. This will lower the total reliability of these areas but gives a more realistic picture of the reliability of the total biological value, as this value is not based on values for all ecosystem components (see above). So the total reliability score ranges from 1 (because the seabird valuation map covers the entire BPNS resulting in a minimum reliability score for a grid of 1 when no data for the other ecosystem components is available for this grid) to 12 (when the values for all ecosystem components are estimated as ‘highly reliable’). These 12 categories were divided into three classes (low, medium and high reliability) again.

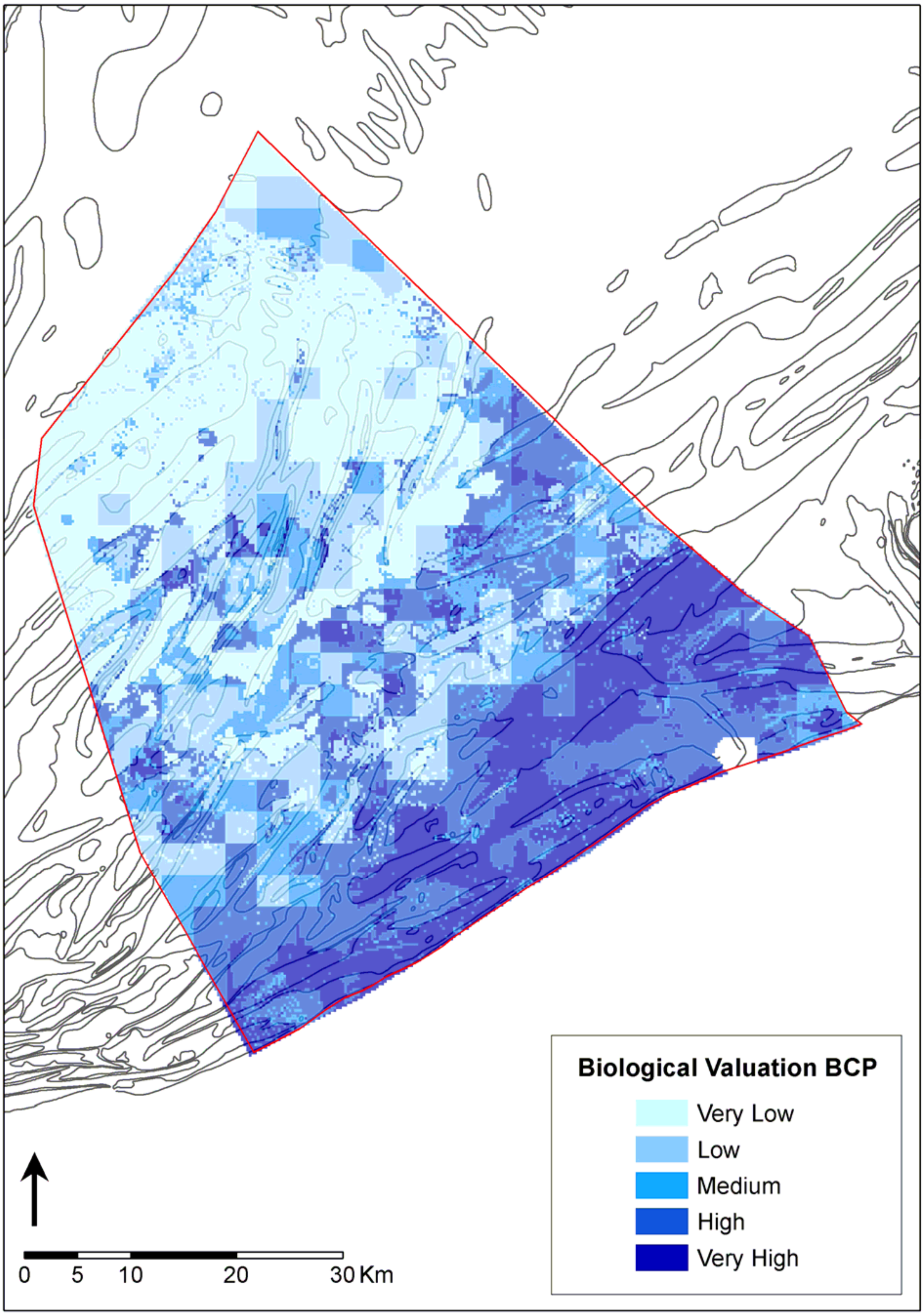


**Figure 10: The marine biological valuation map of the BPNS which integrates the seabird, macrobenthos, epibenthos en demersal fish valuation maps.**

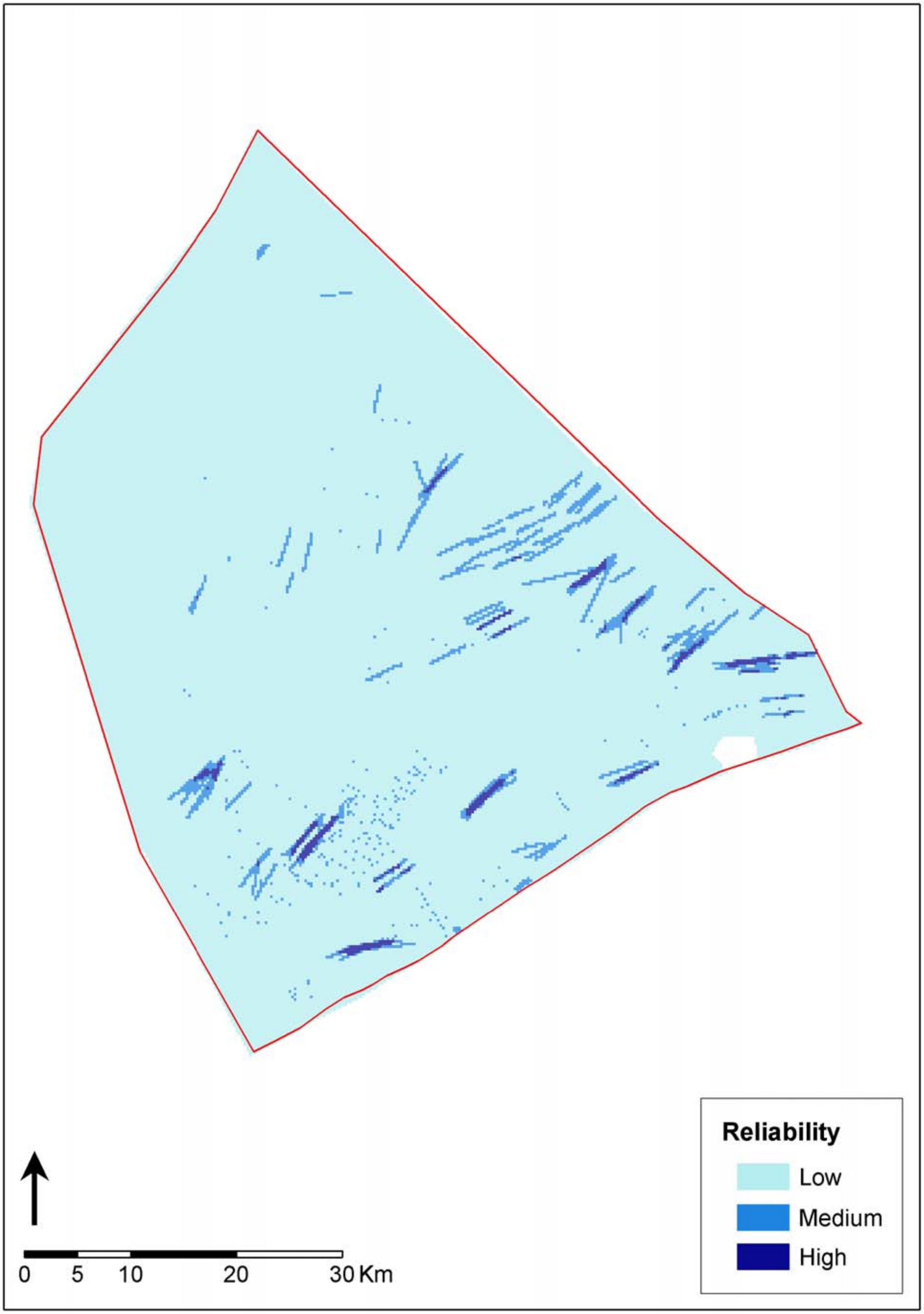


Figure 11: Reliability of the total biological valuation map.

# X. BWZEE Project Website and Online Atlas

## *A. PROJECT WEBSITE*

The project website (http://www.vliz.be/projects/bwzee) is hosted and maintained by VLIZ. The website holds some general information about the project (project outline, partners, different work packages, expected results, state of the art, …). Besides this, some useful information, like reports or presentations from the workshops, can be downloaded from the website. In the metadata section (which is in fact a part of IMIS, the Integrated Marine Information System of VLIZ), information about the different partners (institutes and persons) can be found. Also, the different datasets that were used for the biological valuation are herein described. After all the metadata section contains an overview of relevant literature about the subject of biological valuation.

## *B. ONLINE ATLAS*

VLIZ developed an online dynamic atlas (http://www.vliz.be/projects/bwzee/atlas.php) where all end products (different maps for every question, valuations maps) are available for zooming, querying,… by end-users. Herefore, the open-source software MapServer was used. MapServer, developed by the University of Minnesota, is a technology that makes it possible to render spatial data to the web and to query that spatial data unless the user needs to buy or install complex software. All the actions (zooming, panning, querying,…) happen in a simple web browser. Furthermore, the software is compatible with most of the common web browsers (Internet Explorer, Mozilla Firefox,…).

Figure 12 shows an overview of the atlas (showing the overall Biological Valuation Map). The dynamic atlas is equipped with straightforward tools for zooming, panning and querying the different layers. As can be seen on the example, users can choose which layer(s) are visible on the map. There's a splitting up between reference layers and data layers. The reference layers are only present to give the user an overview the study area. The data layers are all the layers that have been produced in the BWZEE project (the valuation maps, the reliability maps and the different questions). All the data layers can be listed in a popup-window where the user can choose which data layer should be shown in the atlas (see Figure 13 where the Biological Valuation for Seabirds is chosen and shown in the atlas).

The most important tool of the application is the query tool. Clicking the map with the query tool gives an overview of the information in all the layers at the location where one clicked (see Figure 14). With this one can compare the results of the different components (macrobenthos, epibenthos,…) for the same location.

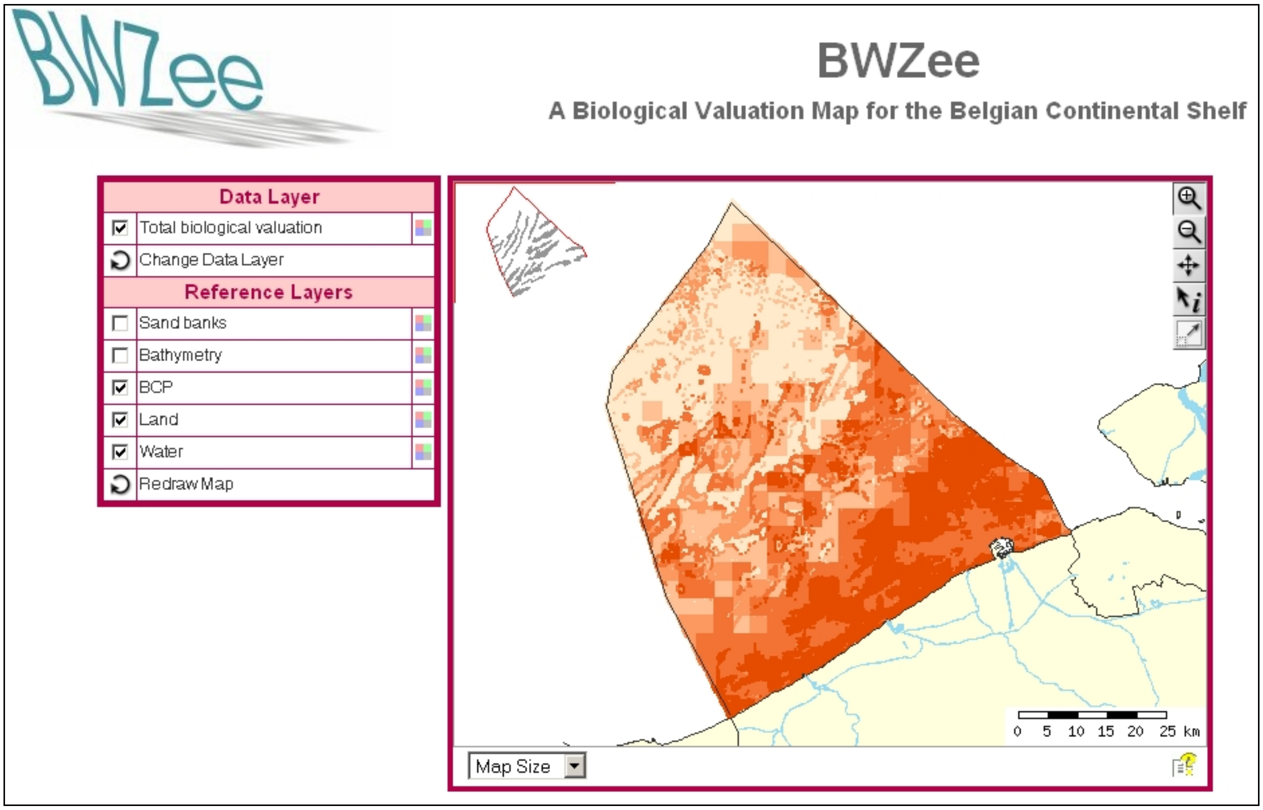


**Figure 12: Overview of the atlas (showing the overall Biological Valuation Map).**

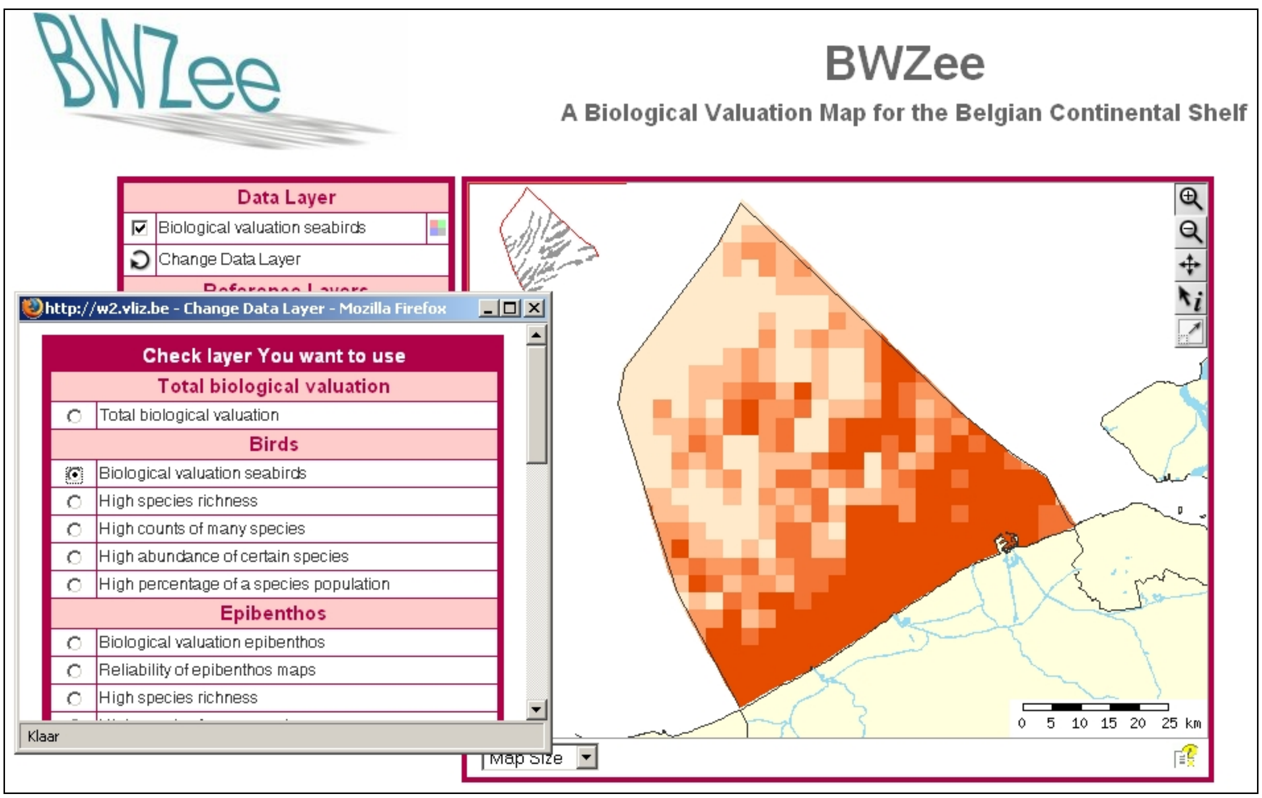


**Figure 13: Pop-up window showing available data layers.**

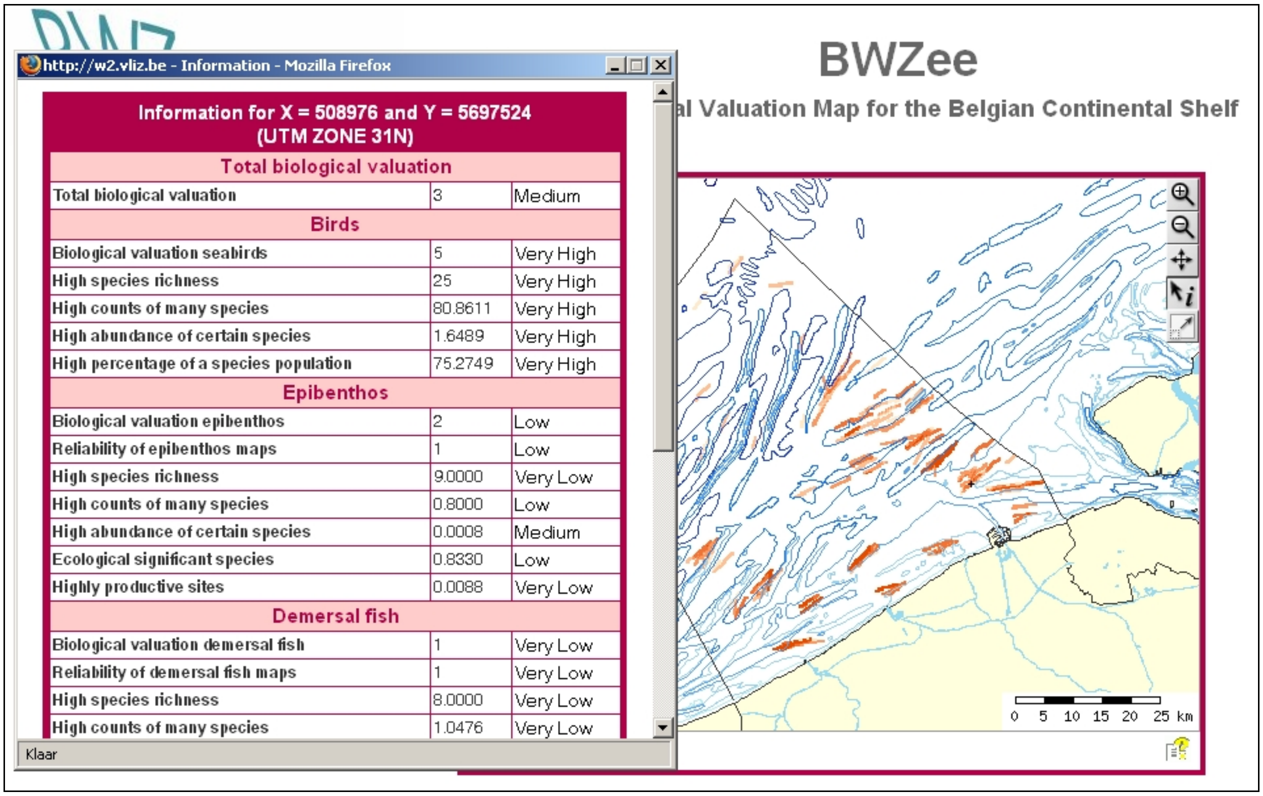


Figure 14: Screen shot of the query tool giving an overview of the information in all the layers at the location.

# XI. General conclusions of the project

The BWZee project aimed at the development of a marine biological valuation map (BVM) for the BPNS. Such map would be useful for policy makers when they have to make decisions on spatial planning. The map should integrate all (or as much as possible) biological information available for the area. Before the start of this project such maps were lacking and one was obliged to base value assessments of the BPNS on the available best expert judgement. Consulting a panel of experts is often an untransparant process which cannot exclude subjectivity.

Chapter I is an overall introduction to the subject of marine biological valuation and describes its importance in marine policy.

Chapter II gives an overview of the concept for marine biological valuation that was developed during the project. The concept is framed around five valuation criteria of which three are first-order criteria (rarity, aggregation, fitness consequences) and two are modifying criteria (naturalness and proportional importance). These criteria were selected based on a literature review of valuation assessments and on the discussions of an international workshop on the topic. The concept allows the assessment of the intrinsic value of the subzones within a study area, on a relative basis. As this biological valuation concept is based on the consensus reached by a group of experts on this matter, it could be possible that refinement of the methodology is needed once it has been evaluated on several case study areas.

Chapter III presents a protocol for the practical application of the marine biological valuation concept to a given study area. When these guidelines are followed they allow the assessment of the biological value of the subzones based on the proposed criteria and with various levels of data availability. After dividing the study area into subzones and collecting the available biological data, the protocol allows the scoring of the valuation criteria by answering specific assessment questions. These questions are relevant for the different criteria and incorporate all organizational levels of biodiversity (from the genetic to the ecosystem level). The protocol should make it possible to determine the biological value of subzones of study areas with various levels of data availability. Clear algorithms were designed for each assessment question which can be used to query the database. Although several scoring systems could be used, chapter II suggests one specific scoring system which was tested on the BPNS data. In the future other scoring methods should also be tested (on BPNS data, but also on other case study areas) to see which one gives the best results.

Chapter IV describes a methodology which enables the development of full-coverage habitat suitability maps for the macrobenthic communities by applying interpolation techniques and habitat modelling, based on point data. Full-coverage maps of the macrobenthic spatial distribution were lacking before the start of this project. Because there was a very good coverage of physical habitat data (median grain size, mud content) for the BPNS, interpolation techniques could be applied to them to produce full-coverage maps of the physical habitat. The relations between these physical parameters and the macrobenthic communities were investigated and this resulted in the Habitat model. This model allows performing the translation from a physical habitat map towards a full-coverage modelled macrobenthic community map.

Chapter V gives an overview of the marine biological valuation of the seabirds of the BPNS. Four different assessment questions could be answered for this ecosystem component. Interpolation of data allowed developing full-coverage valuation maps for seabirds. The resulting valuation map for seabirds shows the high ornithological value of the coastal zone. Other, less expected, areas with a high value for seabirds seemed to be the Thornton bank, areas north of the Vlakte van de Raan and parts of the Hinder banks.

Chapter VI gives an overview of the marine biological valuation of the macrobenthos of the BPNS. Eight assessment questions could be answered for this ecosystem component. Interpolation and predictive modelling allowed developing full-coverage probability maps of the macrobenthic communities, which could be used for one assessment question. All other assessment questions could only be answered by using sample point data. The resulting valuation map for macrobenthos also indicated a high values for the coastal zone, the area north of the Thornton Bank and the area between the Vlaamse and the Hinder banks.

Chapter VII gives an overview of the marine biological valuation of the epibenthos of the BPNS. Five assessment questions could be answered for this ecosystem component. Due to a limited epibenthic sampling coverage of the BPNS no full-coverage maps could be constructed and valuation could only be done for specific sampling points. The resulting valuation map for epibenthos indicated that the highest biological values were found in the coastal area while the Vlaamse and Zeeland banks had an intermediate to high value.

Chapter VIII gives an overview of the marine biological valuation of the demersal fish of the BPNS. Three assessment questions could be answered for this ecosystem component. Due to a limited sampling coverage for demersal fish no full-coverage maps could be made by using extrapolation techniques. The valuation could therefore only be made for specific sampling points. The resulting valuation map for demersal fish indicated that areas with a high to very high biological value were found all over the BPNS. The lowest values were calculated for the offshore deeper areas and the eastern coastal zone between Oostende and the mouth of the Westerschelde.

Chapter IX describes the overall marine biological valuation map for the BPNS, which integrates the valuation maps of seabirds, macrobenthos, epibenthos and demersal fish. This map visualizes the high biological value of the coastal zone and the lower value of the offshore area. The reliability of this map is also displayed and high reliability is related to sampling and survey intensity of the BPNS.

Chapter X describes the BWZee project website, which was designed and hosted by VLIZ. This website integrates all interim reports of the project, metadata about the partners and used data, presentations and workshop reports. VLIZ also developed an online dynamic atlas which allows browsing the different valuation maps of each ecosystem component, the valuation maps for each assessment question, the reliability maps and the final integrated biological valuation map for the BPNS. There is also a query tool available to search for data of a specific point of the BPNS for all different layers.

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## *F. CHAPTER VII*

MARLIN website, http://www.marlin.ac.uk

**BWZee**

# A biological valuation map for the Belgian part of the North Sea


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**Final report – February 2007**

**ANNEXES**


1 Marine Biology Section
Department of Biology
University of Ghent

2 Renard Centre of
Marine Geology
University of Ghent

3 Institute of Nature
Conservation

4 Sea Fisheries
Department

5 Flanders Marine
Institute



BELGIAN FEDERAL SCIENCE POLICY OFFICE
SECOND MULTIANNUAL SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY – SPSD II
PART II – GLOBAL CHANGE, ECOSYSTEMS AND BIODIVERSITY

Contract Number EV/02/37

## LIST OF ANNEXES

## *A. Appendix 1 from chapter II: Overview of existing ecological criteria for selection of valuable marine areas or marine areas in need of protection.*

| Criterion | Occurrence in literature | Included in final set of criteria? |
|---|---|---|
| **Rarity** | EC Bird Directive (1979); Smith and Theberge (1986); Mitchell (1987); Bergman *et al.* (1991); HELCOM (1992); Fairweather and McNeill (1993); Norse (1993); Tunesi and Diviacco (1993); IUCN (1994); Gilman (1997); Vanderklift *et al.* (1998); IMO (1999); RAMSAR COP 7 (1999); Laffoley *et al.* (2000b); Turpie *et al.* (2000); UNEP (2000); Woodhouse *et al.* (2000); Ardron *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); Gilman (2002); Hiscock *et al.* (2003); Sanderson (1996a, 1996b); Connor *et al.* (2002); OSPAR (2003); Roberts *et al.* (2003a, 2003b) | Yes, 1st order criterion |
| **(Bio)diversity** | Ray (1984); Smith and Theberge (1986); Mitchell (1987); Bergman *et al.* (1991); HELCOM (1992); Fairweather and McNeill (1993); Norse (1993); Tunesi and Diviacco (1993); IUCN (1994); Chaillou *et al.* (1996); Sanderson (1996b); Gilman (1997); Hockey and Branch (1997); Brody (1998); Vanderklift *et al.* (1998); Zacharias and Howes (1998); RAMSAR COP 7 (1999); Ray (1999); Laffoley *et al.* (2000b); Turpie *et al.* (2000); UNEP (2000); Woodhouse *et al.* (2000); Eaton (2001); Rachor and Günther (2001)[a]; Ardron *et al.* (2002); Connor *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); Gilman (2002); GTZ GmbH (2002); Rey Benayas and de la Montaña (2003); Roberts *et al.* (2003a, 2003b); Roff *et al.* (2003); Breeze (2004); JNCC (2004) | Not as criterion, but all organizational levels of biodiversity are implicitly included in the valuation strategy (see text for explanation) |
| **Naturalness** | Ray (1984); Smith and Theberge (1986); Mitchell (1987); Fairweather and McNeill (1993); Sanderson (1996b); Gilman (1997); Hockey and Branch (1997); Brody (1998); IMO (1999); Laffoley *et al.* (2000b); Rachor and Günther (2001)[a]; Connor *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); Gilman (2002); GTZ GmbH (2002); Breeze (2004); JNCC (2004) | Yes, modifying criterion |
| **Proportional importance** | Ray (1984); Hockey and Branch (1997); Laffoley *et al.* (2000b); Connor *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); Lieberknecht *et al.* (2004a, 2004b); OSPAR (2003) | Yes, modifying criterion |
| | EC Habitats Directive (1992) | Yes, under 'fitness consequences' and 'aggregation', 1st order criteria |
| **Ecosystem functioning** | EC Habitats Directive (1992) ; RAMSAR COP 7 (1999) | Yes, under 'fitness consequences', 1st order criterion |
| **Reproductive/ bottleneck areas** | Breeze (2004) | |
| **Density** | EC Habitats Directive (1992); Chaillou *et al.* (1996); Zacharias and Howes (1998); RAMSAR COP 7 (1999); Connor *et al.* (2002); Beck *et al.* (2003) ; Beger *et al.* (2003) | Yes, under 'aggregation', 1st order criterion |
| **Dependency** | UNESCO (1972); Hockey and Branch (1997); Gilman (1997, 2002) | |
| | Ray (1984); UNEP (1990); IUCN (1994); Barcelona Convention (1995); Laffoley *et al.* (2000b); UNEP (2000); Department for Environment, Food and Rural Affairs (2002); OSPAR (2003); Roberts *et al.* (2003a, 2003b) | Yes, under 'fitness consequences', 1st order criterion |
| | EC Bird Directive (1979); Ray (1984); Mitchell (1987); HELCOM (1992); IUCN (1994); Brody (1998); IMO (1999); RAMSAR COP 7 (1999); UNEP (2000); Rachor and Günther (2001); Connor *et al.* (2002); GTZ GmbH (2002); Beck *et al.* (2003); Hiscock *et al.* (2003); Roberts *et al.* (2003a, 2003b) ; Breeze (2004); JNCC (2004) | Yes, under 'aggregation' and 'fitness consequences', 1st order criteria |
| **Productivity** | Ray (1984); Smith and Theberge (1986); Mitchell (1987); Fairweather and McNeill (1993); Norse (1993); Chaillou *et al.* (1996); Brody (1998); Vanderklift *et al*. (1998); Zacharias and Howes (1998); IMO (1999); Rachor and Günther (2001)[a]; BTZ GmbH (2002); Beck *et al.* (2003); Breeze (2004); JNCC (2004) | |
| **Special features present** | Smith and Theberge (1986); Fairweather and McNeill (1993); Norse (1993); Zacharias and Howes (1998); Vanderklift *et al.* (1998) | |
| | Tunesi and Diviacco (1993); Beck *et al.* (2003); OSPAR (2003) | Yes, under 'rarity', 1st order criterion |
| **Uniqueness** | UNESCO (1972); EC Bird Directive (1979); Tunesi and Diviacco (1993); Gilman (1997); Brody (1998); Zacharias and Howes (1998); IMO (1999); Rachor and Günther (2001)[a]; Ardron *et al.* (2002); Connor *et al.* (2002); Gilman (2002); GTZ GmbH (2002); Mouillot *et al.* (2002) | |
| **Irreplaceability** | MacDonald *et al.* (1996); Beger *et al.* (2003); Leslie *et al.* (2003) | |
| **Isolation** | EC Habitats Directive (1992) (more used in terrestrial environments) | |

| | | |
|---|---|---|
| **Extent of habitat type** | Mitchell (1987); EC Habitats Directive (1992); Hiscock *et al.* (2003) | Yes, under 'proportional importance', modifying criterion |
| **Biogeography** | Hiscock *et al.* (2003) | |
| | Hockey and Branch (1997); Turpie *et al.* (2000); Beger *et al.* (2003); Roberts *et al.* (2003a, 2003b) | No, MPA selection criteria |
| **Representativeness** | Ray (1984); Mitchell (1987); Bergman *et al.* (1991); EC Habitats Directive (1992); Fairweather and McNeill (1993); Sanderson (1996b); Gilman (1997); Hockey and Branch (1997); Brody (1998); Laffoley *et al.* (2000b); Rachor and Günther (2001)[a]; Ardron *et al.* (2002); Gilman (2002); GTZ GmbH (2002); Leslie *et al.* (2003); Roberts *et al.* (2003a, 2003b); JNCC (2004) | No, MPA selection criteria |
| **Integrity** | Ray (1984); Mitchell (1987); IUCN (1994); Brody (1998); IMO (1999); Rachor and Günther (2001)[a]; GTZ GmbH (2002) | |
| **Vulnerability** | UNESCO (1972); EC Bird Directive (1979); Smith and Theberge (1986); Mitchell (1987); UNEP (1990); Bergman *et al.* (1991); EC Habitats Directive (1992); HELCOM (1992); IUCN (1994); Barcelona Convention (1995); MacDonald *et al.* (1996); Gilman (1997); Hockey and Branch (1997); Brody (1998); RAMSAR COP 7 (1999); Laffoley *et al.* (2000b); UNEP (2000); Bax and Williams (2001); Rachor and Günther (2001)[a]; Department for Environment, Food and Rural Affairs (2002); Gilman (2002); GTZ GmbH (2002); Hiscock *et al.* (2003); OSPAR (2003); Roberts *et al.* (2003a, 2003b); Breeze (2004); JNCC (2004) | No, related to 'resilience' criterion which is excluded from final list of valuation criteria (see above) |
| **Decline** | Laffoley *et al.* (2000b); Connor *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); OSPAR (2003) | |
| **Recovery potential** | Mitchell (1987); Laffoley *et al.* (2000b); Department for Environment, Food and Rural Affairs (2002) | |
| **Degree of threat** | EC Bird Directive (1979); Majeed (1987); Mitchell (1987); Bergman *et al.* (1991); Dauer (1993); MacDonald *et al.* (1996); Gilman (1997); Batabyal (1999); Eaton (2001); Connor *et al.* (2002); Gilman (2002); McLaughlin *et al.* (2002); Roberts *et al.* (2003a, 2003b) | No, management criterion |
| **Protection level** | Bergman *et al.* (1991); Zacharias and Howes (1998) | |
| **International significance** | Brody (1998) | |
| **Economic interest** | Hockey and Branch (1997); Roberts *et al.* (2003a, 2003b) | No, socio-economic criterion |

[a]Modified and complemented after Salm and Clark (1984), Salm and Price (1995) and Kelleher (1999)

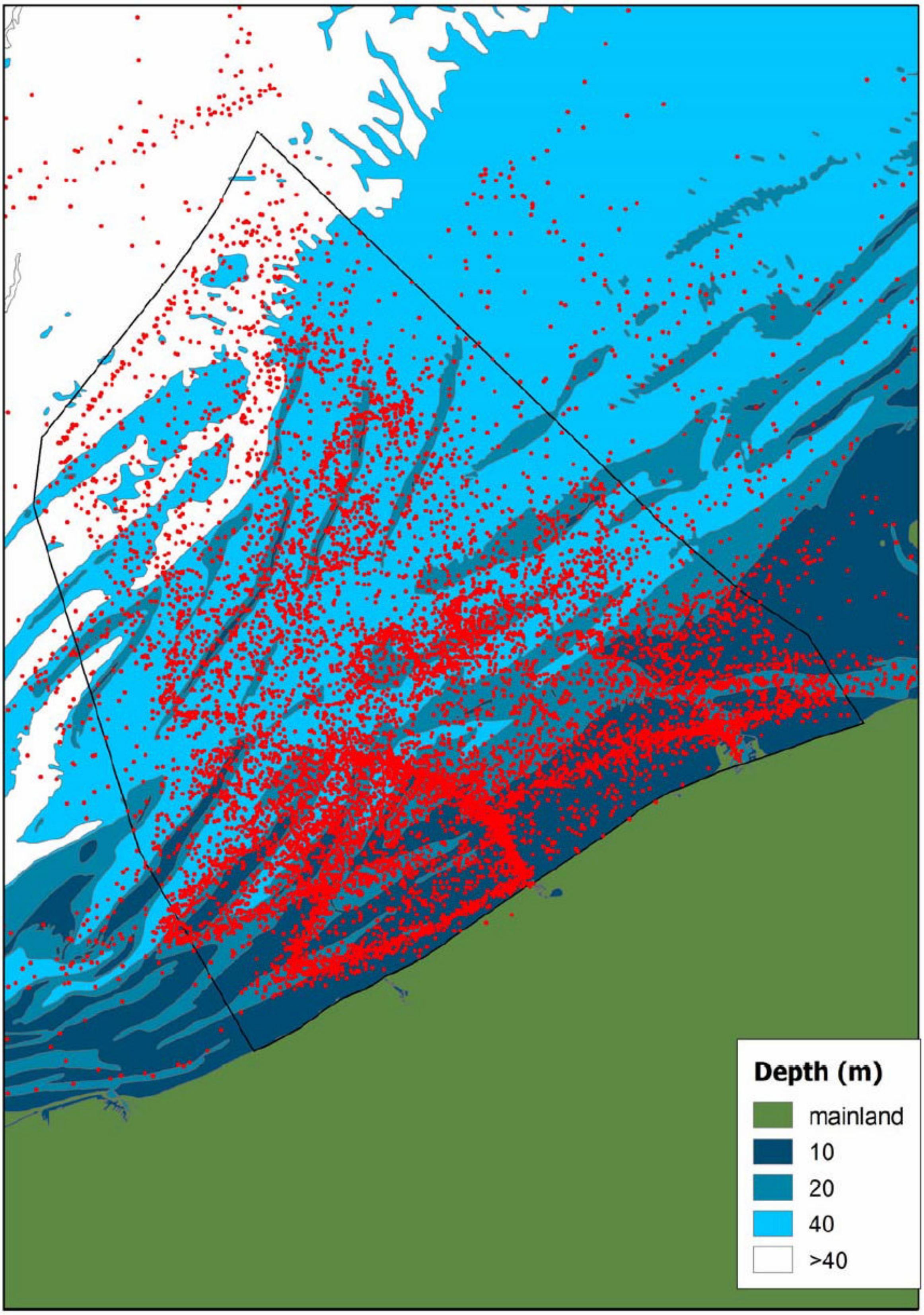
## B. Appendix 1 from chapter III: Criteria-assessment scheme according to the different organizational levels of biodiversity.

| Organizational level of biodiversity | Rarity | Aggregation | Fitness consequences | Naturalness | Proportional importance |
|---|---|---|---|---|---|
| **Genetic level - structure** | - Is there a high diversity of **gene pools/genetic stocks** present in the subzone? = Are there **genetically variable individuals** occurring in the subzone? | | - Is there a high diversity of **gene pools/genetic stocks** present in the subzone? = Are there **genetically variable individuals** occurring in the subzone? | | |
| **Genetic level - processes** | | | | | |
| | | - Is a **high percentage of a species population** located within the subzone?<br>- Is the **abundance** of a certain species very high in the subzone (= is there a concentration/aggregation of the species in the subzone)? | | | - Is a **high percentage of a species population** located within the subzone? |
| **Species/ population level - structure** | - Is the subzone characterised by high counts of **rare species**?<br>- Are there habitats formed by **keystone species** present in the subzone?<br>- Are there ecological significant **(keystone) species** with a controlling influence on the community present in the subzone? | - Is the subzone characterised by **high counts of many species**?<br>- Is the abundance of **focal species** (as a surrogate for biodiversity in general?) high in the subzone?<br>- Are there habitats formed by **keystone species** present in the subzone? | - Is the abundance of **focal species** (as a surrogate for biodiversity in general?) high in the subzone?<br>- Are there habitats formed by **keystone species** present in the subzone?<br>- Are there ecological significant **(keystone) species** with a controlling influence on the community present in the subzone?<br>- Are there critical sites for the preservation of certain **indicator species** present in the subzone? | - Are there habitats formed by **keystone species** present in the subzone?<br>- Is species diversity in the area dominated by **native species**? | - Is a **species** (with an otherwise restricted **distribution** within the study area or wider region) present in high densities within the subzone? |

| | | | | |
|---|---|---|---|---|
| **Species/ population level - processes** | | - Are there important **migration routes** for certain species located within the subzone?<br>- Are there sites present in the subzone that provide **refuge** during adverse conditions?<br>- Are there **wintering/resting/ feeding sites** located in the subzone?<br>- Are there critical (key) **sites for reproduction (spawning/breeding)** present in the subzone?<br>- Are there critical (key) **sites for recruitment (nursery/rearing)** present in the subzone? | - Are there important **migration routes** for certain species located within the subzone?<br>- Are there sites present in the subzone that provide **refuge** during adverse conditions?<br>- Are there **wintering/resting/ feeding sites** located in the subzone?<br>- Are there critical (key) **sites for reproduction (spawning/breeding)** present in the subzone? | |
| **Community level - structure** | - Is the **species richness** in the subzone high?<br>- Are there **distinctive/unique communities** present in the subzone?<br>- Are there **endemic species** present in the subzone? | - Is the **species richness** in the subzone high? | - Is the **species richness** in the subzone high? | - Are there **invasive species** present in the subzone?<br>- Is the subzone's species diversity dominated by **invasive (and/or cultured) species**? |
| **Community level - processes** | | | | |
| **Ecosystem level - Structure** | - Is the subzone characterized by a **complex topography** or **seabed morphology**? | | | |
| | - Is the **substrate diversity** in the subzone high?<br>- Is the subzone an outstanding example representing **significant geological processes** in the development of landforms?<br>- Are there **distinctive/unique ecosystems** located in the subzone?<br>- Are there sites present in the subzone which are critical for **nutrient cycling**? | - Are there sites present in the subzone which are critical for **nutrient cycling**? | | |

| | | | | |
|---|---|---|---|---|
| **Ecosystem level - Structure** | - Are there sites present in the subzone where **nutrient retention** occurs?<br><br>- Are there any **unique/distinctive oceanographic features/processes** located in the subzone? | - Are there sites present in the subzone where **nutrient retention** occurs? | | |
| | Are there **upwelling** sites located in the subzone? | - Is the subzone highly (naturally) **productive**? | - Is the subzone highly (naturally) **productive**? | |
| **Ecosystem level - processes** | | | | - Are there subzones where **no human disturbance** takes place or where **no habitat degradation** has taken place?<br>- Are there **pristine areas** or **reference areas for the natural condition** of the habitat(s) present in the subzone? |

***C. Positions of 10-minute counts for seabirds in the BPNS between 1992 and 2005.***



## *D. Table 1 and 2 for seabirds*

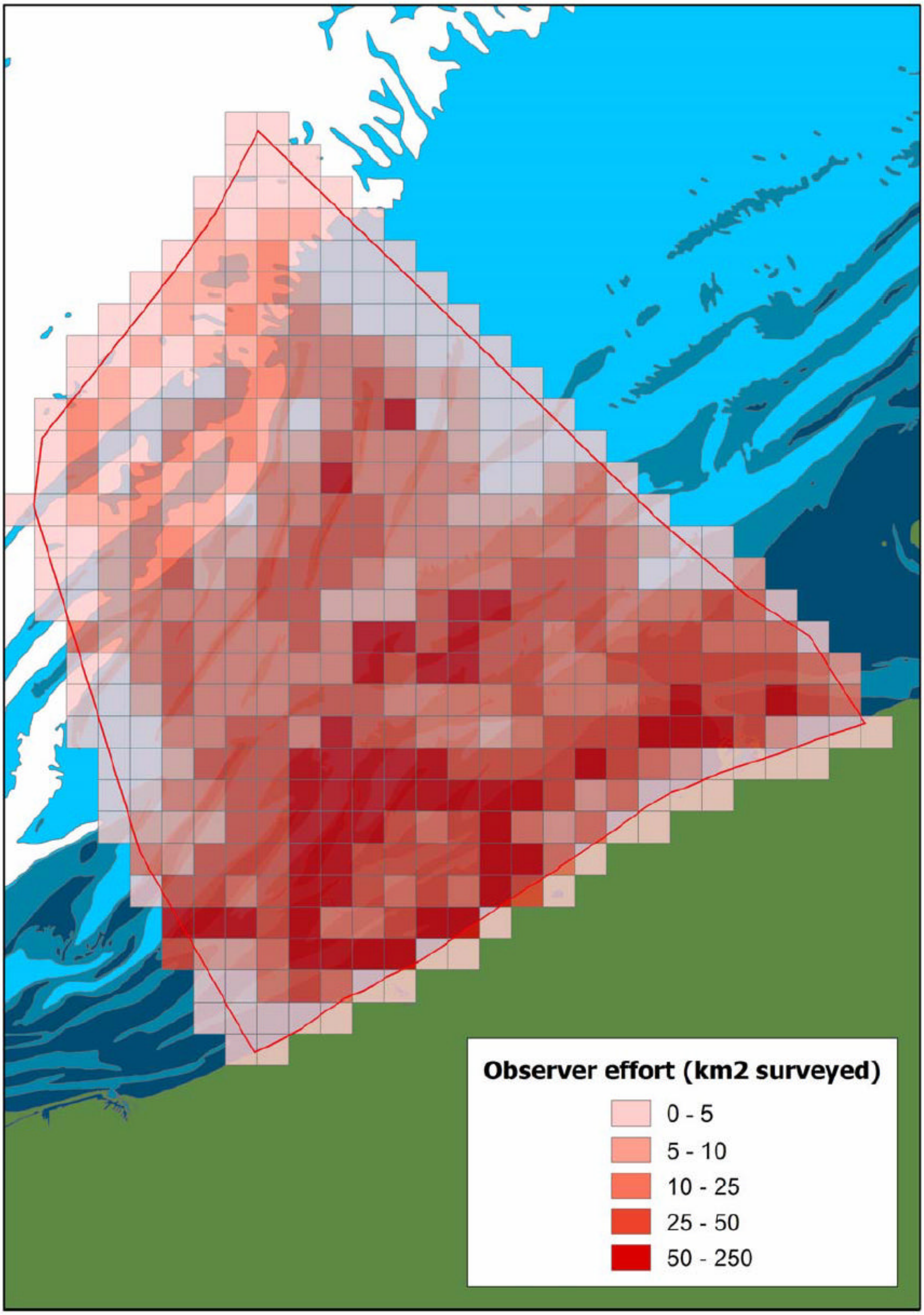
**Table 1.** Number of poskeys in which a species was observed (on a total of 15.908). The species selected for density calculations ('common' species) are indicated in blue.

| Species | Number of poskeys |
|---|---|
| Lesser Black-backed Gull | 5187 |
| Herring Gull | 4837 |
| Great Black-backed Gull | 4726 |
| Kittiwake | 4592 |
| Common Guillemot | 4316 |
| Common Gull | 3925 |
| Northern Gannet | 3705 |
| Little Gull | 2175 |
| Northern Fulmar | 1361 |
| Razorbill | 1287 |
| Red-throated Diver | 1245 |
| Sandwich Tern | 1225 |
| Black-headed Gull | 1185 |
| Common Tern | 1089 |
| Great Crested Grebe | 983 |
| Common Scoter | 869 |
| Great Cormorant | 516 |
| Great Skua | 430 |
| Arctic Skua | 137 |
| Black-throated Diver | 88 |
| Common Eider | 81 |
| Pomarine Skua | 46 |
| Sooty Shearwater | 43 |
| Black Tern | 42 |
| Arctic Tern | 35 |
| Velvet Scooter | 33 |
| Mediterranean Gull | 30 |
| Yellow-legged Gull | 24 |
| Little Tern | 24 |
| Red-breasted Merganser | 23 |
| Leach's Storm-petrel | 17 |
| Puffin | 10 |
| Manx Shearwater | 8 |
| Red-necked Grebe | 7 |
| European Storm-Petrel | 6 |
| Shag | 6 |
| Greater Scaup | 4 |
| Long-tailed Skua | 3 |
| Sabine's Gull | 3 |
| Black-necked Grebe | 2 |
| Gull-billed Tern | 2 |
| Little Auk | 2 |
| Great Northern Diver | 1 |
| Cory's Shearwater | 1 |
| Mediterranean Shearwater | 1 |
| Iceland Gull | 1 |
| Black Guillemot | 1 |

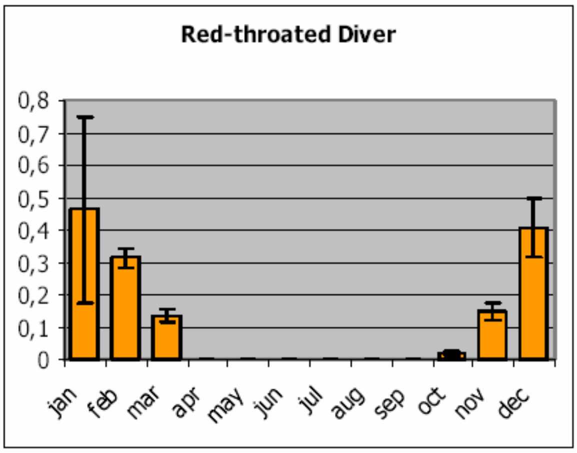
**Table 2.** Total number of birds observed of each species. The species selected for density calculations ('common' species) are indicated in blue.

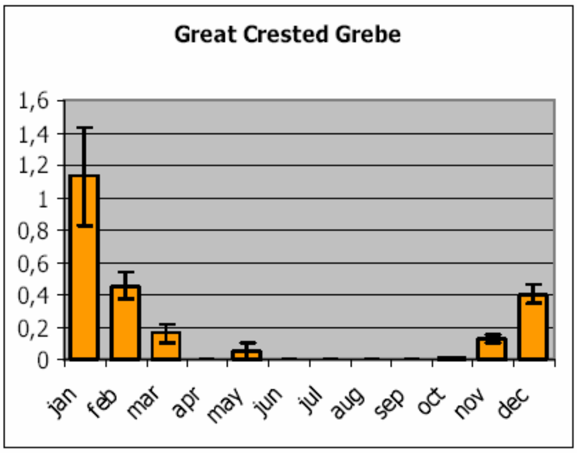
| Species | Number of birds |
|---|---|
| Lesser Black-backed Gull | 82215 |
| Herring Gull | 66341 |
| Common Scoter | 47178 |
| Common Gull | 40667 |
| Kittiwake | 33096 |
| Great Black-backed Gull | 31385 |
| Common Guillemot | 20149 |
| Black-headed Gull | 17769 |
| Northern Gannet | 16855 |
| Common Tern | 12933 |
| Little Gull | 12320 |
| Northern Fulmar | 8639 |
| Sandwich Tern | 5379 |
| Great Crested Grebe | 4369 |
| Razorbill | 3359 |
| Red-throated Diver | 3357 |
| Common Eider | 2436 |
| Great Cormorant | 2241 |
| Great Skua | 526 |
| Velvet Scooter | 383 |
| Arctic Skua | 194 |
| Black Tern | 117 |
| Greater Scaup | 114 |
| Red-breasted Merganser | 103 |
| Black-throated Diver | 94 |
| Arctic Tern | 85 |
| Sooty Shearwater | 60 |
| Little Tern | 57 |
| Pomarine Skua | 48 |
| Mediterranean Gull | 33 |
| Yellow-legged Gull | 26 |
| Leach's Storm-petrel | 19 |
| Little Auk | 13 |
| Red-necked Grebe | 10 |
| Puffin | 10 |
| Manx Shearwater | 9 |
| European Storm-Petrel | 6 |
| Shag | 6 |
| Black-necked Grebe | 3 |
| Long-tailed Skua | 3 |
| Sabine's Gull | 3 |
| Gull-billed Tern | 2 |
| Great Northern Diver | 1 |
| Cory's Shearwater | 1 |
| Mediterranean Shearwater | 1 |
| Iceland Gull | 1 |
| Black Guillemot | 1 |

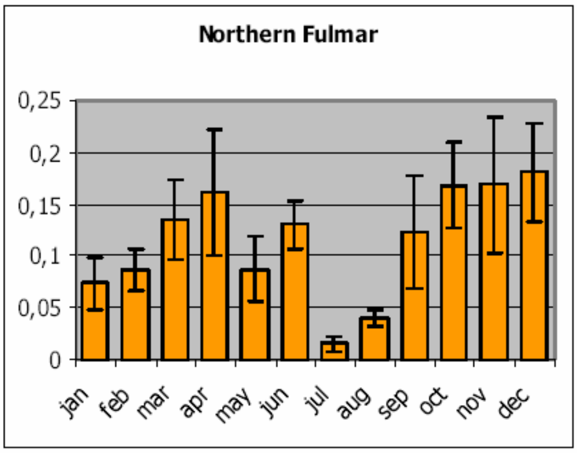
***E. Observer effort for seabirds on 3x3 km square level (number of square kilometers surveyed).***

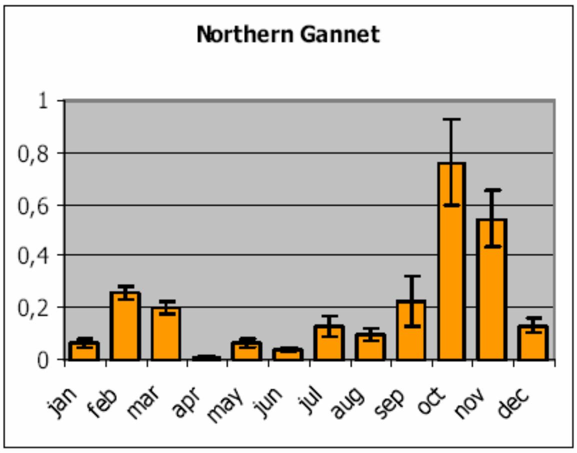


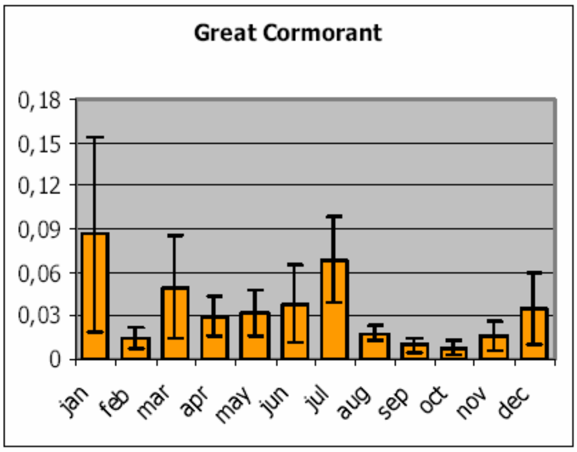
## *F. Mean densities per month of each seabird species*

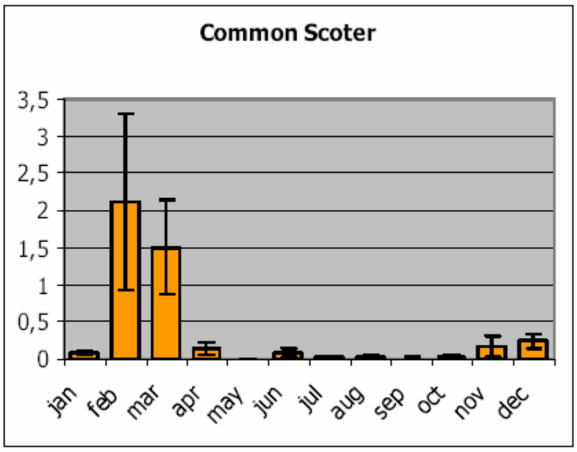


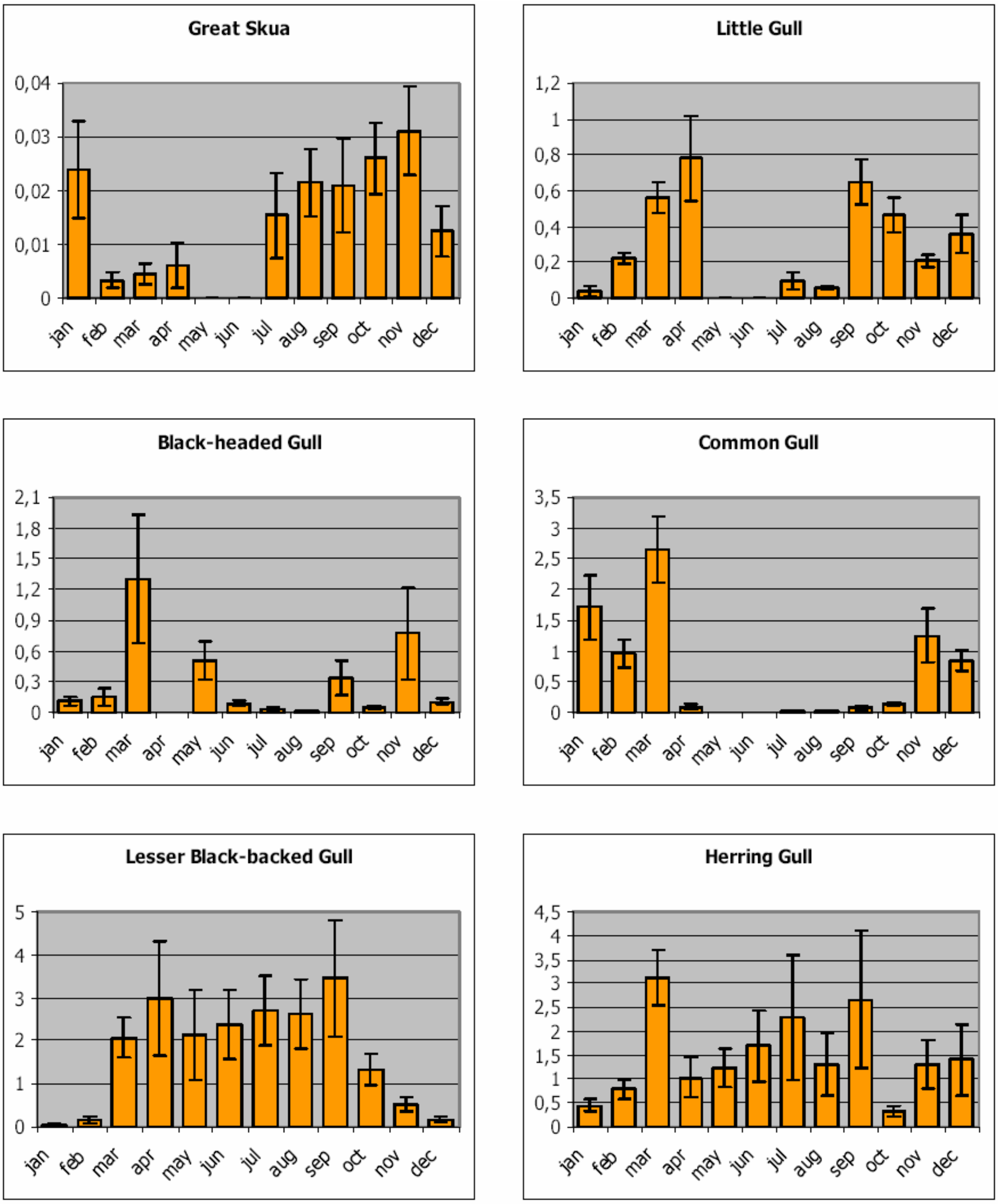



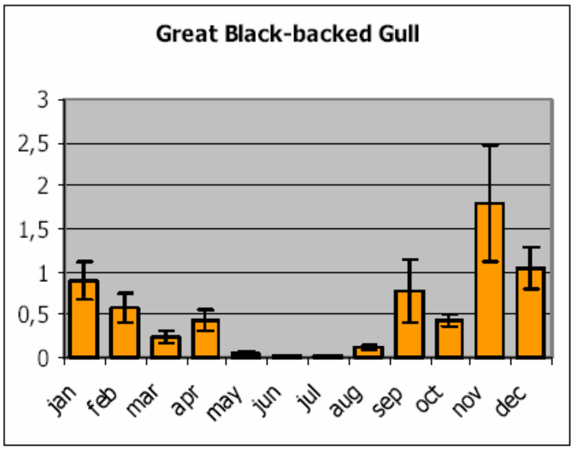



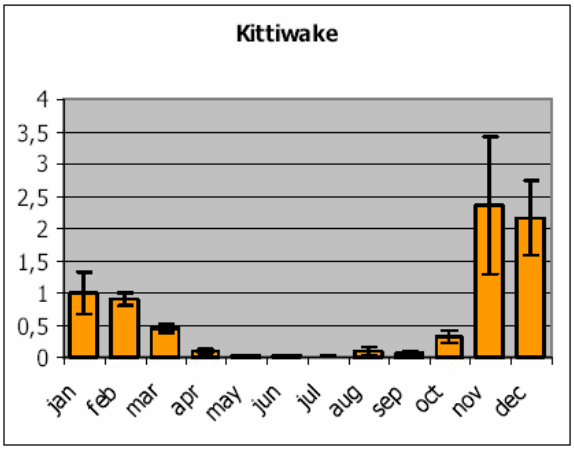



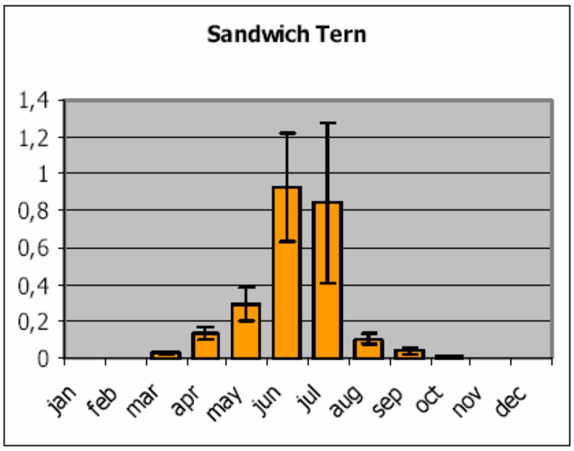



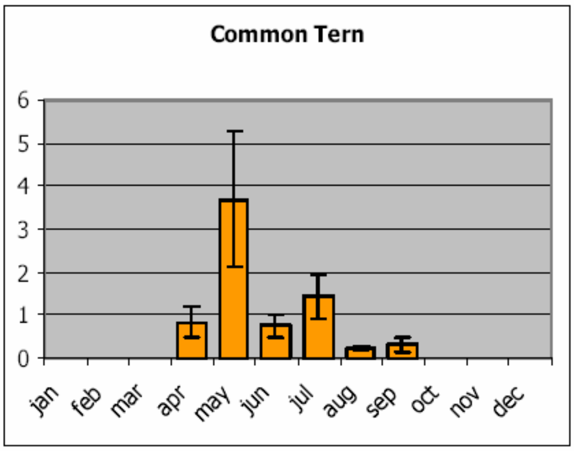



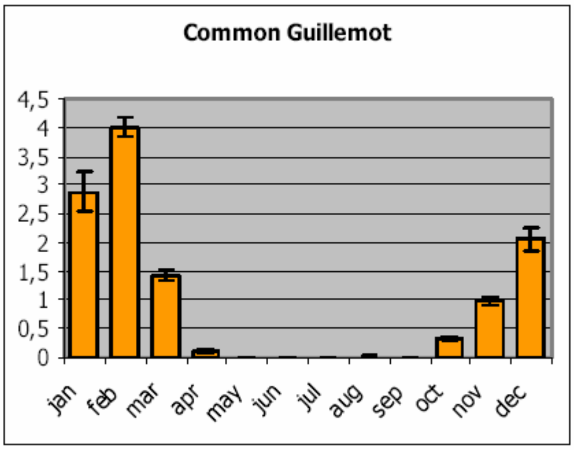

Great Skua
0,04
0,03
0,02
0,01
0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Little Gull
1,2
1
0,8
0,6
0,4
0,2
0
Black-headed Gull
2,1
1,8
1,5
1,2
0,9
0,6
0,3
0
Common Gull
3,5
3
2,5
2
1,5
1
0,5
0
Lesser Black-backed Gull
5
4
3
2
1
0
Herring Gull
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

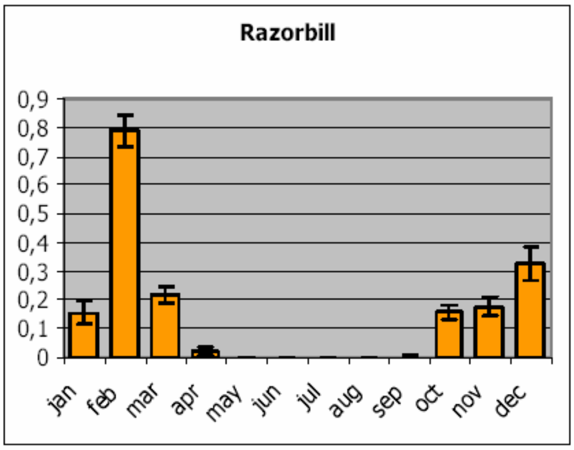

Great Black-backed Gull
0
0,5
1
1,5
2
2,5
3
jan feb mar apr may jun jul aug sep oct nov dec


Kittiwake
0
0,5
1
1,5
2
2,5
3
3,5
4
jan feb mar apr may jun jul aug sep oct nov dec


Sandwich Tern
0
0,2
0,4
0,6
0,8
1
1,2
1,4
jan feb mar apr may jun jul aug sep oct nov dec


Common Tern
0
1
2
3
4
5
6
jan feb mar apr may jun jul aug sep oct nov dec


Common Guillemot
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
jan feb mar apr may jun jul aug sep oct nov dec

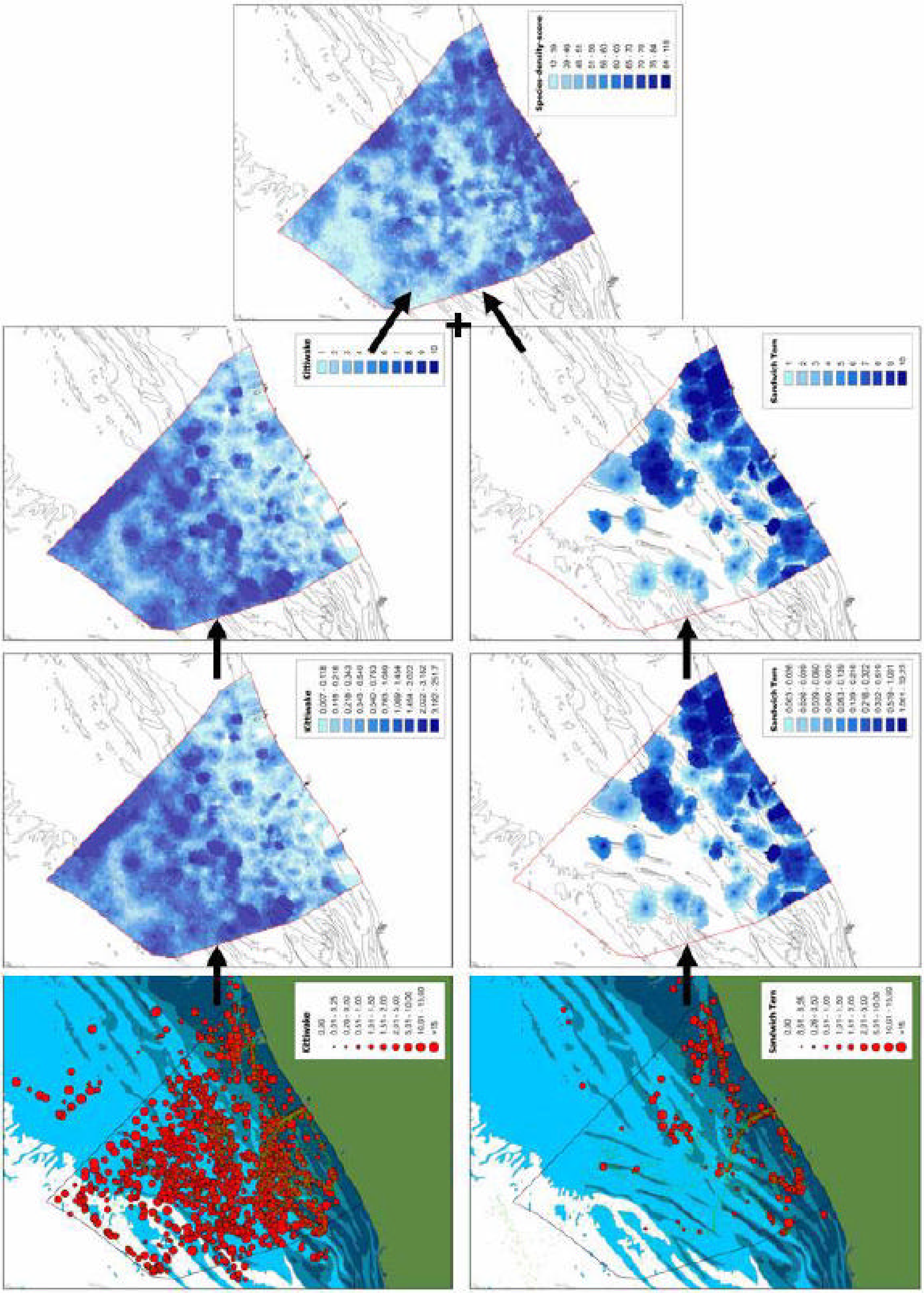

Razorbill
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
jan feb mar apr may jun jul aug sep oct nov dec

**G. Mean density per month of each seabird species and overview of the months retained for further analysis (indicated in green).**

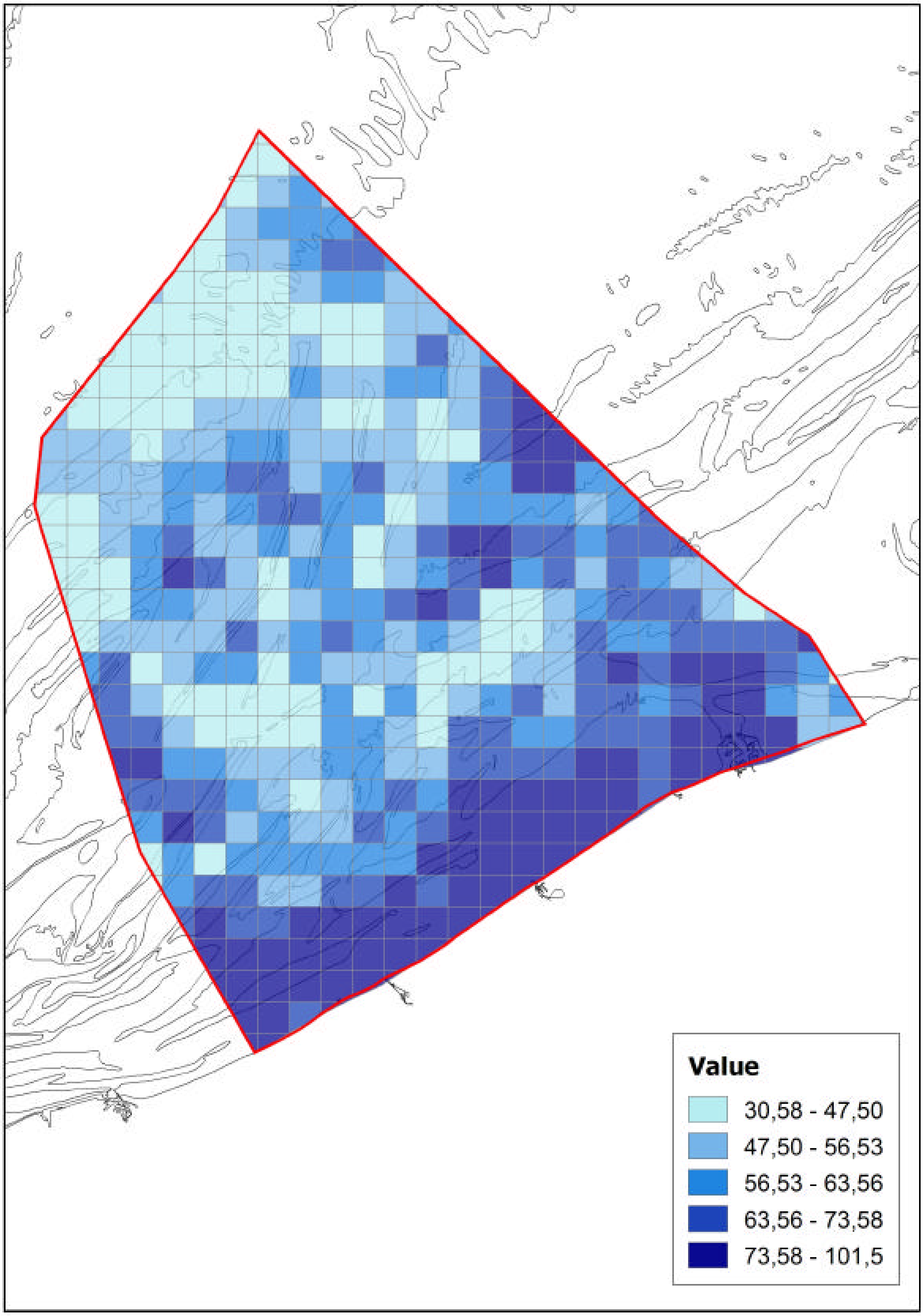
| Month | Red-throated Diver | Great Crested Grebe | Northern Fulmar | Northern Gannet | Great Cormorant | Common Scoter | Great Skua | Little Gull | Black-headed Gull | Common Gull |
|---|---|---|---|---|---|---|---|---|---|---|
| jan | 0,462 | 1,135 | 0,074 | 0,065 | 0,087 | 0,090 | 0,024 | 0,038 | 0,110 | 1,711 |
| feb | 0,314 | 0,458 | 0,086 | 0,258 | 0,014 | 2,123 | 0,003 | 0,220 | 0,159 | 0,967 |
| mar | 0,134 | 0,162 | 0,135 | 0,202 | 0,050 | 1,509 | 0,005 | 0,559 | 1,306 | 2,661 |
| apr | 0,000 | 0,000 | 0,162 | 0,012 | 0,030 | 0,144 | 0,006 | 0,782 | 0,004 | 0,095 |
| may | 0,000 | 0,055 | 0,087 | 0,065 | 0,032 | 0,000 | 0,000 | 0,000 | 0,505 | 0,004 |
| jun | 0,000 | 0,000 | 0,130 | 0,039 | 0,038 | 0,081 | 0,000 | 0,000 | 0,093 | 0,003 |
| jul | 0,000 | 0,000 | 0,016 | 0,129 | 0,069 | 0,017 | 0,015 | 0,096 | 0,035 | 0,017 |
| aug | 0,000 | 0,000 | 0,041 | 0,096 | 0,018 | 0,033 | 0,021 | 0,058 | 0,013 | 0,015 |
| sep | 0,000 | 0,000 | 0,123 | 0,223 | 0,010 | 0,009 | 0,021 | 0,649 | 0,335 | 0,071 |
| okt | 0,017 | 0,008 | 0,167 | 0,759 | 0,008 | 0,040 | 0,026 | 0,461 | 0,044 | 0,146 |
| nov | 0,146 | 0,129 | 0,169 | 0,544 | 0,016 | 0,168 | 0,031 | 0,209 | 0,772 | 1,251 |
| dec | 0,406 | 0,405 | 0,180 | 0,132 | 0,034 | 0,243 | 0,012 | 0,356 | 0,106 | 0,834 |

| Month | Lesser Black-backed Gull | Herring Gull | Great Black-backed Gull | Kittiwake | Sandwich Tern | Common Tern | Common Guillemot | Razorbill |
|---|---|---|---|---|---|---|---|---|
| jan | 0,054 | 0,448 | 0,887 | 1,002 | 0,000 | 0,000 | 2,870 | 0,154 |
| feb | 0,175 | 0,790 | 0,581 | 0,903 | 0,000 | 0,000 | 4,005 | 0,789 |
| mar | 2,075 | 3,115 | 0,237 | 0,448 | 0,029 | 0,001 | 1,423 | 0,216 |
| apr | 2,979 | 1,019 | 0,440 | 0,092 | 0,134 | 0,834 | 0,118 | 0,021 |
| may | 2,156 | 1,230 | 0,045 | 0,020 | 0,293 | 3,692 | 0,003 | 0,000 |
| jun | 2,364 | 1,692 | 0,019 | 0,023 | 0,929 | 0,767 | 0,005 | 0,000 |
| jul | 2,699 | 2,288 | 0,016 | 0,012 | 0,843 | 1,436 | 0,000 | 0,000 |
| aug | 2,630 | 1,308 | 0,118 | 0,098 | 0,102 | 0,228 | 0,016 | 0,000 |
| sep | 3,459 | 2,658 | 0,785 | 0,057 | 0,044 | 0,326 | 0,000 | 0,002 |
| okt | 1,318 | 0,335 | 0,439 | 0,323 | 0,008 | 0,015 | 0,335 | 0,158 |
| nov | 0,519 | 1,308 | 1,784 | 2,353 | 0,000 | 0,000 | 0,981 | 0,175 |
| dec | 0,180 | 1,404 | 1,040 | 2,157 | 0,000 | 0,000 | 2,054 | 0,326 |

### *H. Methodology to answer the question "Is the subarea characterized by high counts of many species" for seabirds.*



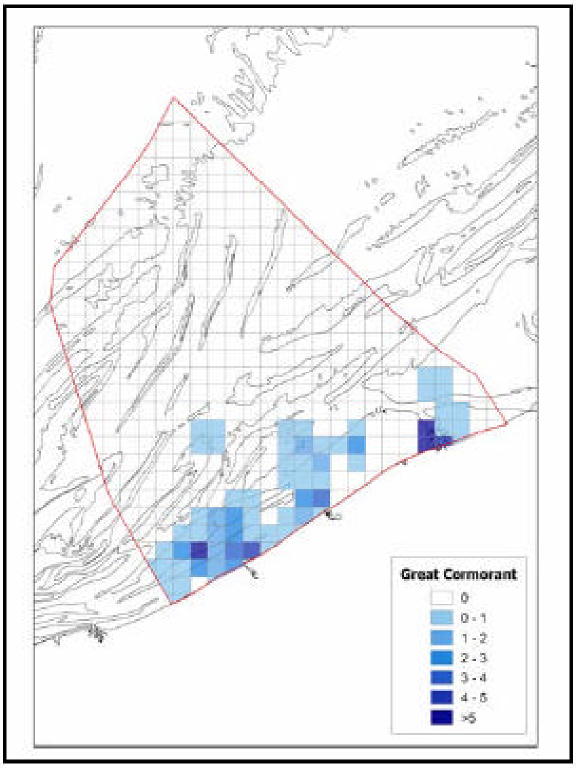
## I. Species density map for seabirds

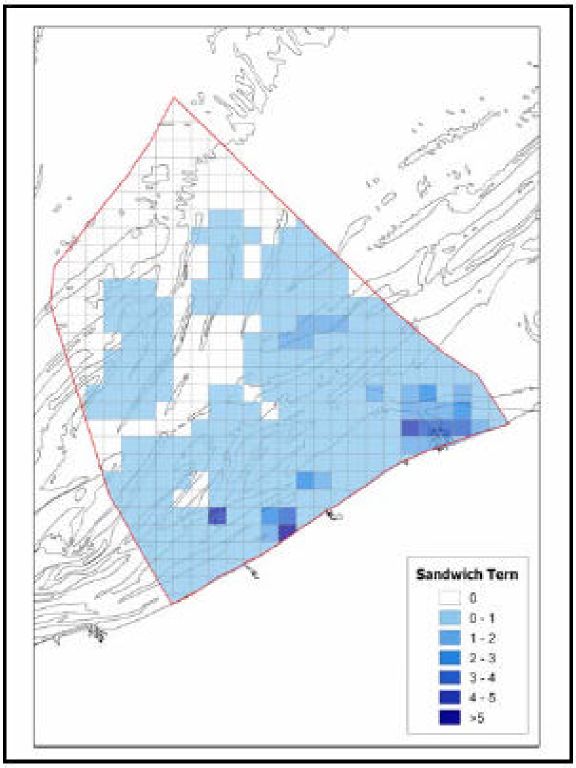


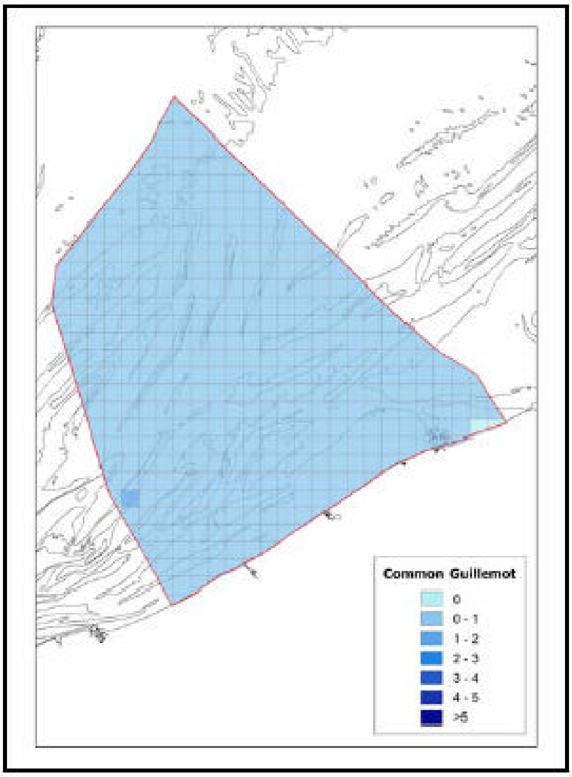
## *J. Mean number of each species present in the BPNS, % of the biogeographical population, total % occurring in the most important 5% of the 3x3 km-grid-cells, number of grid-cells with presence and aggregation coefficient.*

| Species | Number of birds on the BPNS | Percentage of the biogeographical population occurring on the BPNS | Total percentage of birds occurring in the 5% most important 3x3 km-grid-cells | Number of 3x3 km-grid-cells with presence of the species | Aggregationcoefficient |
|---|---|---|---|---|---|
| Red-throated Diver | 594 | 0,1 | 32 | 348 | 0,09 |
| Great Crested Grebe | 904 | 0,2 | 46 | 173 | 0,26 |
| Northern Fulmar | 884 | 0 | 35 | 338 | 0,1 |
| Northern Gannet | 2117 | 0,2 | 26 | 397 | 0,07 |
| Great Cormorant | 66 | 0 | 84 | 73 | 1,16 |
| Common Scoter | 4444 | 0,3 | 92 | 113 | 0,81 |
| Great Skua | 120 | 0,3 | 32 | 282 | 0,11 |
| Little Gull | 1038 | 1,2 | 33 | 342 | 0,1 |
| Black-headed Gull | 916 | 0 | 91 | 115 | 0,79 |
| Common Gull | 3875 | 0,2 | 43 | 431 | 0,1 |
| Kittiwake | 5697 | 0,1 | 37 | 441 | 0,08 |
| Herring Gull | 4963 | 0,5 | 48 | 430 | 0,11 |
| Great Black-backed Gull | 2840 | 0,6 | 43 | 440 | 0,1 |
| Lesser Black-backed Gull | 5105 | 1 | 38 | 440 | 0,09 |
| Sandwich Tern | 751 | 0,4 | 52 | 292 | 0,18 |
| Common Tern | 1883 | 1 | 72 | 232 | 0,31 |
| Common Guillemot | 9008 | 0,1 | 15 | 438 | 0,03 |
| Razorbill | 1673 | 0,1 | 22 | 400 | 0,06 |

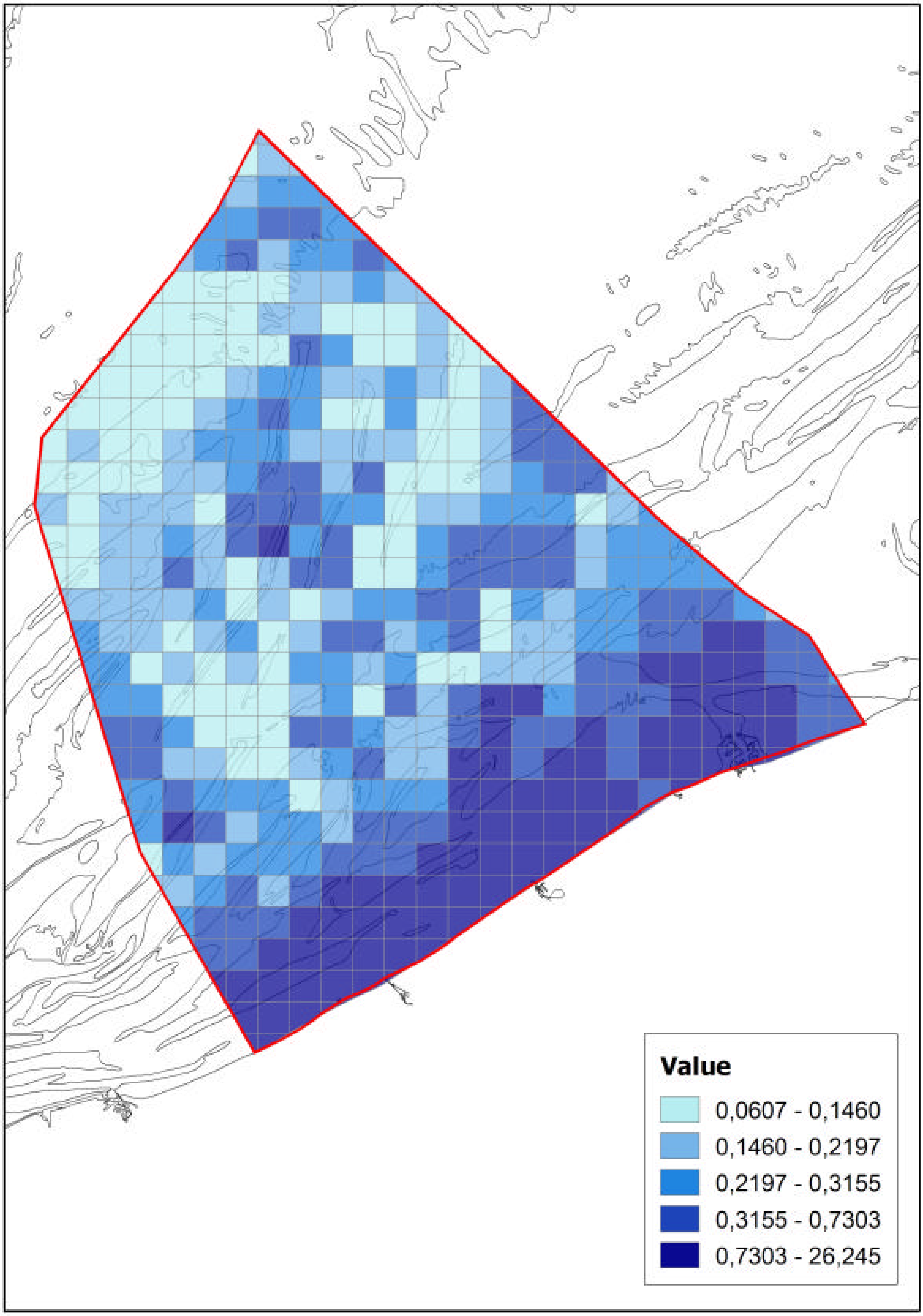
***K. Examples of aggregation maps of Great Cormorant (very aggregated), Sandwich Tern (moderately aggregated) and Common Guillemot (not aggregated).***



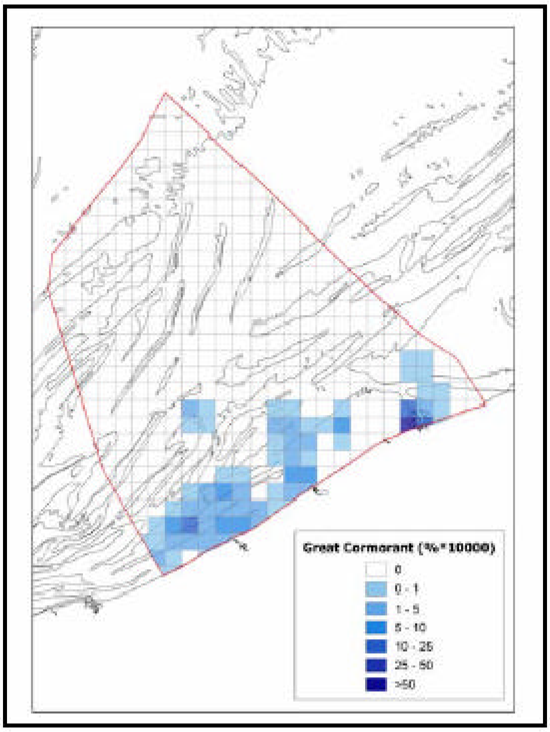



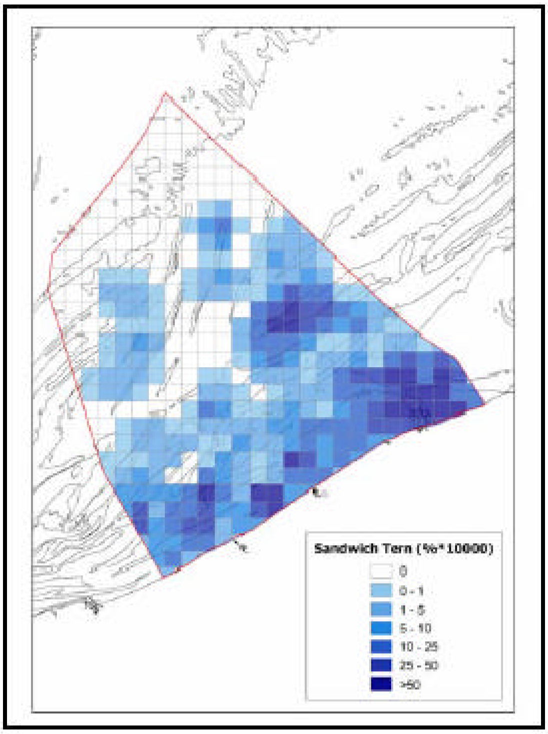



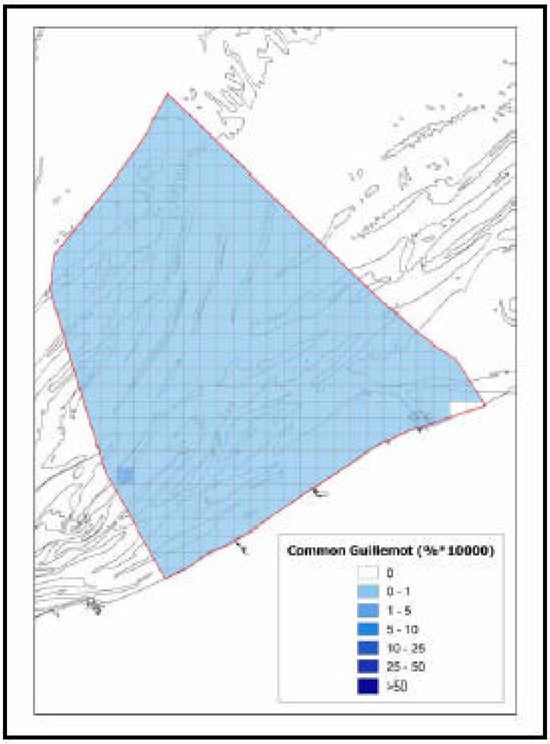
## L. The aggregation map for seabirds.



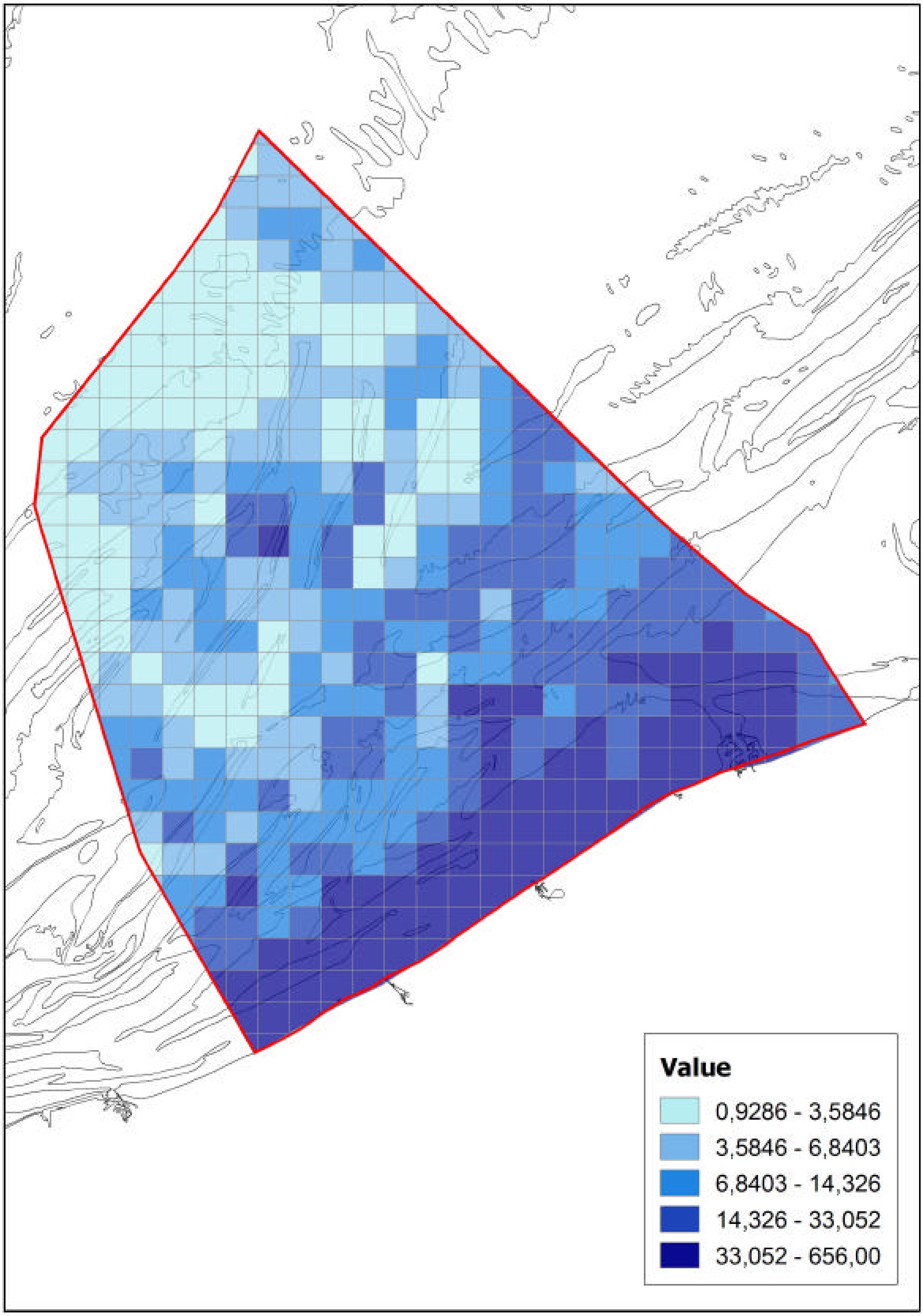
## M. Examples of biopopulation maps of Great Cormorant, Sandwich Tern and Common Guillemot.



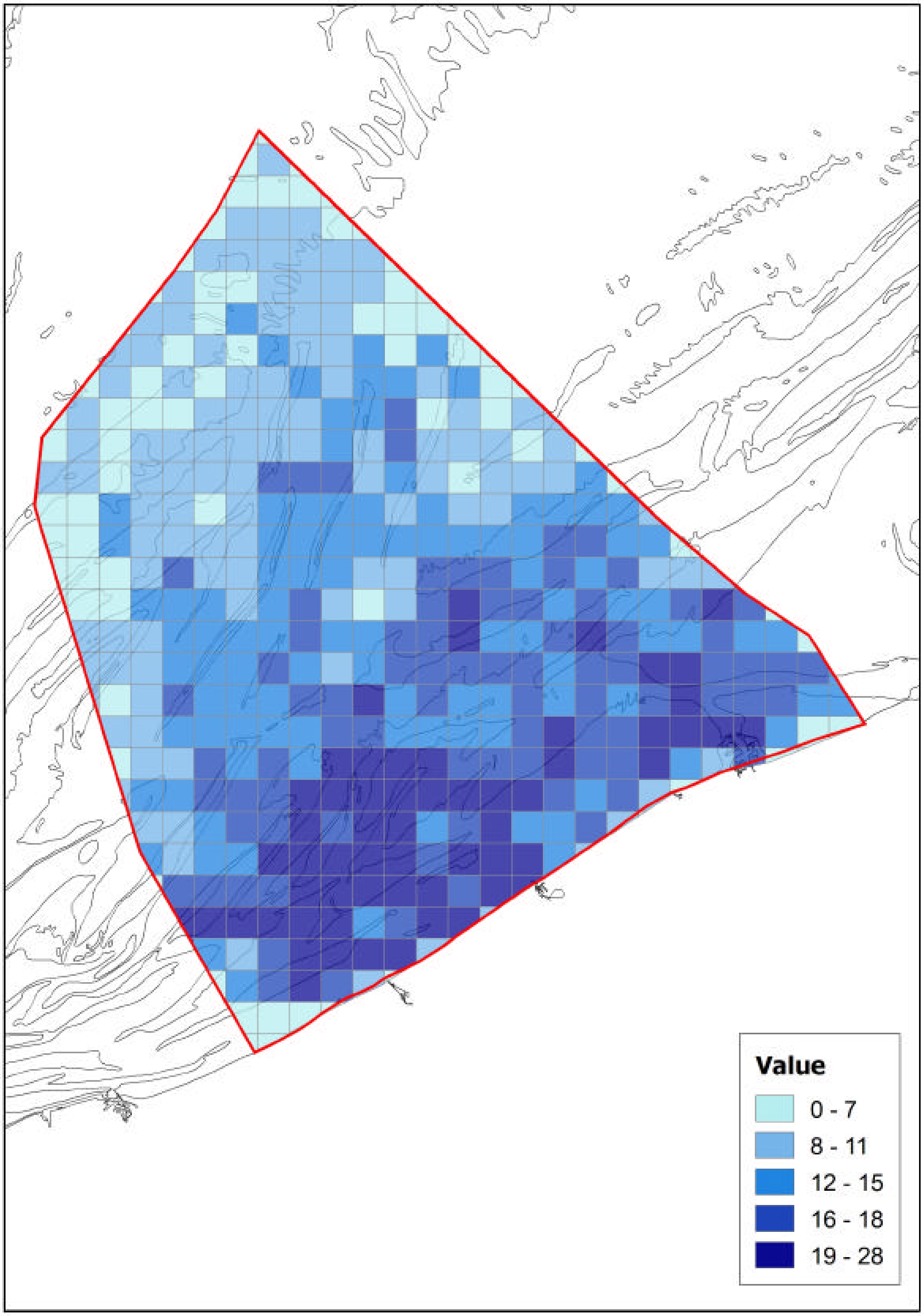



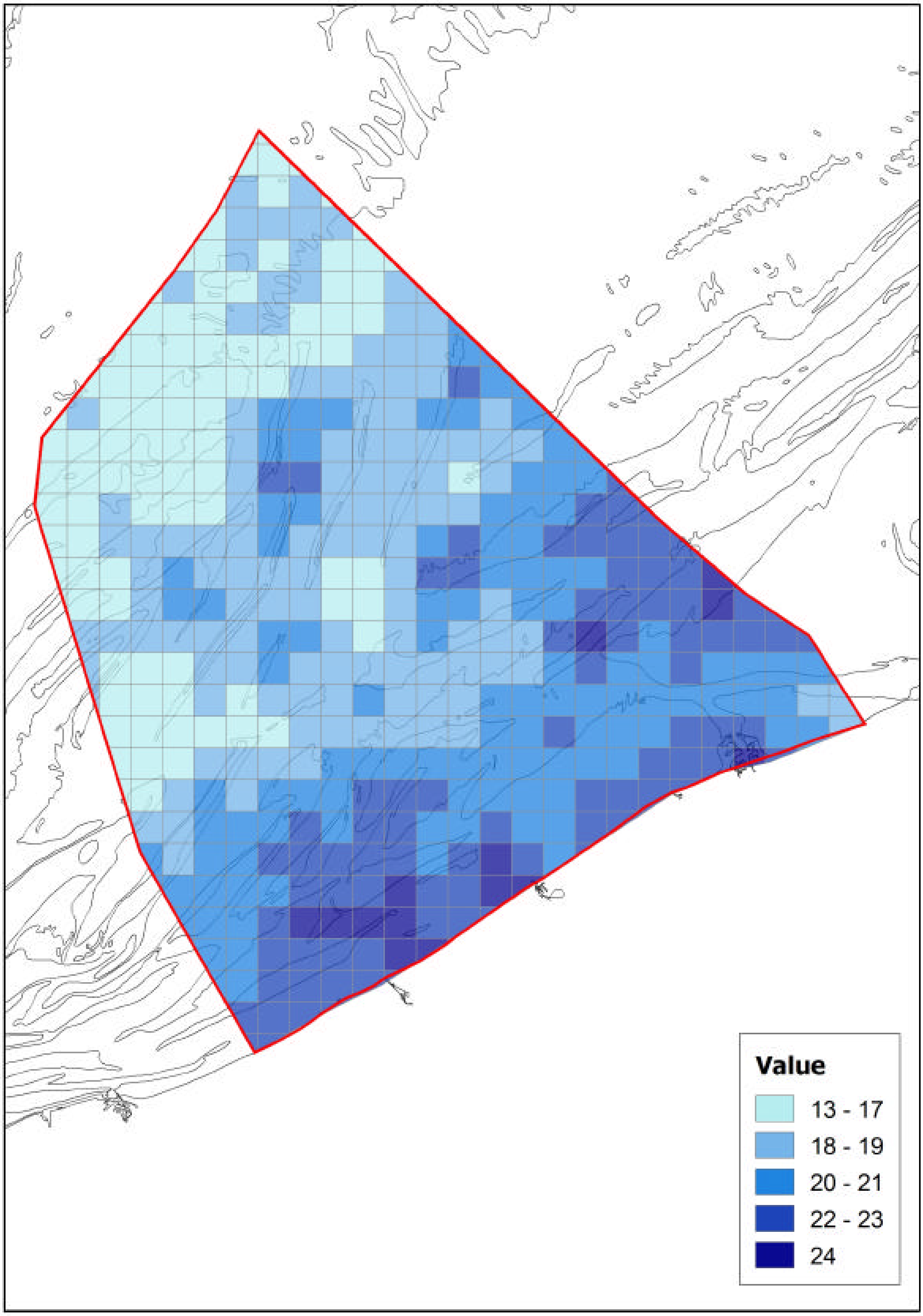
### *N. The biopopulation map for seabirds.*



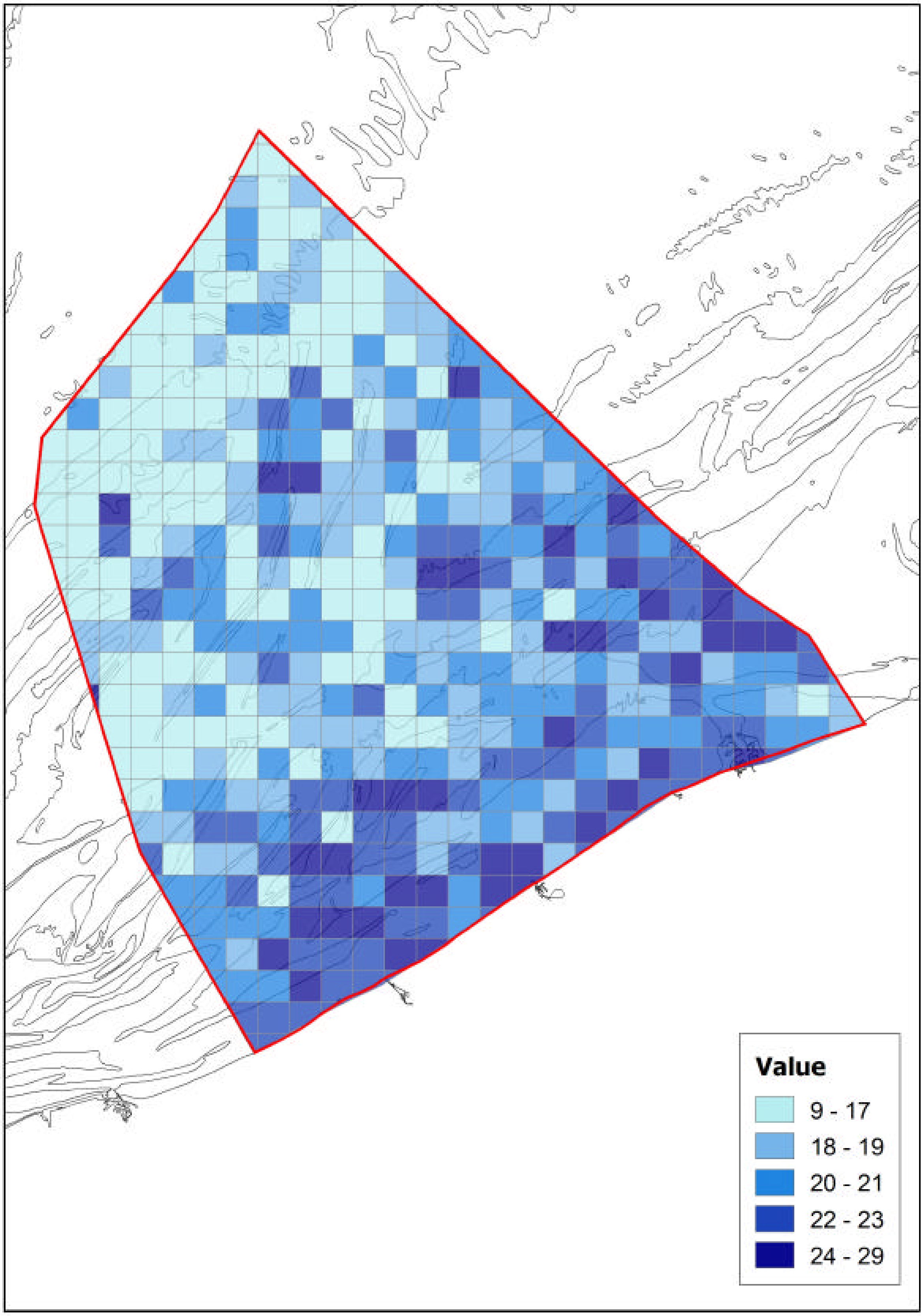
***O. Observed number of seabird species in the 3x3 km grid cells.***



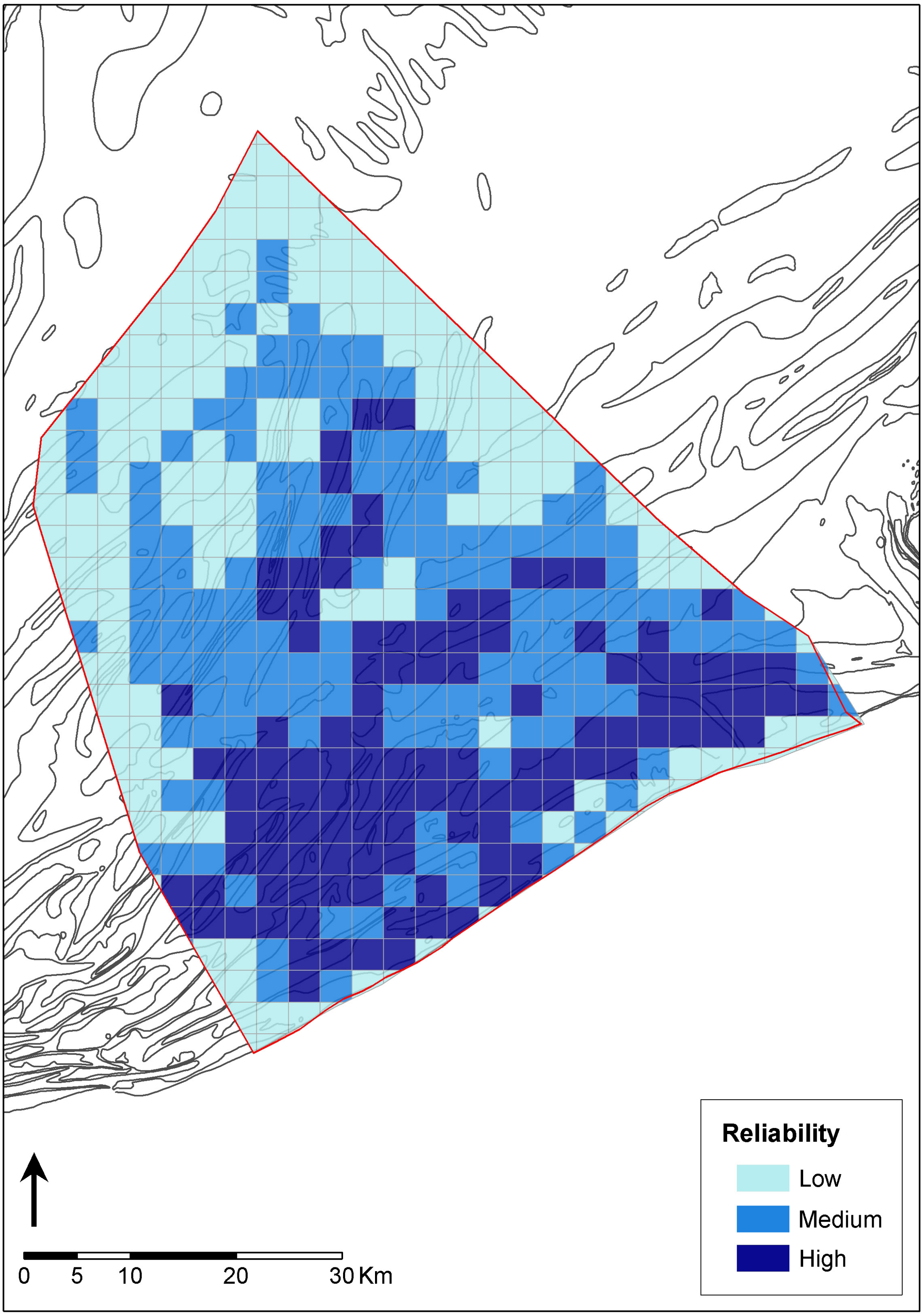
***P. Modelled number of seabird species in the 3x3 km grid cells.***



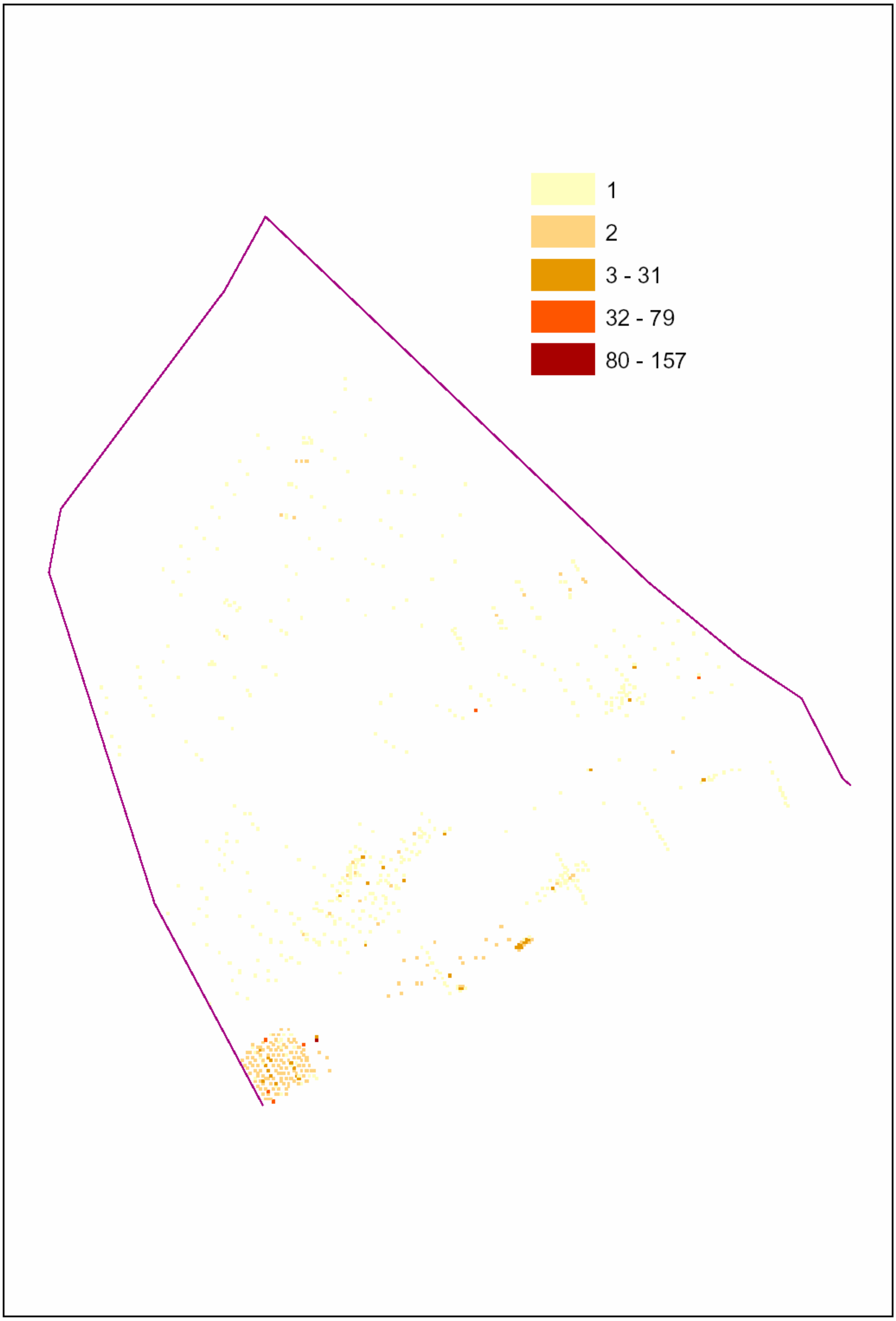
### *Q. The biodiversity map for seabirds.*



### *R. The reliability map for seabirds.*

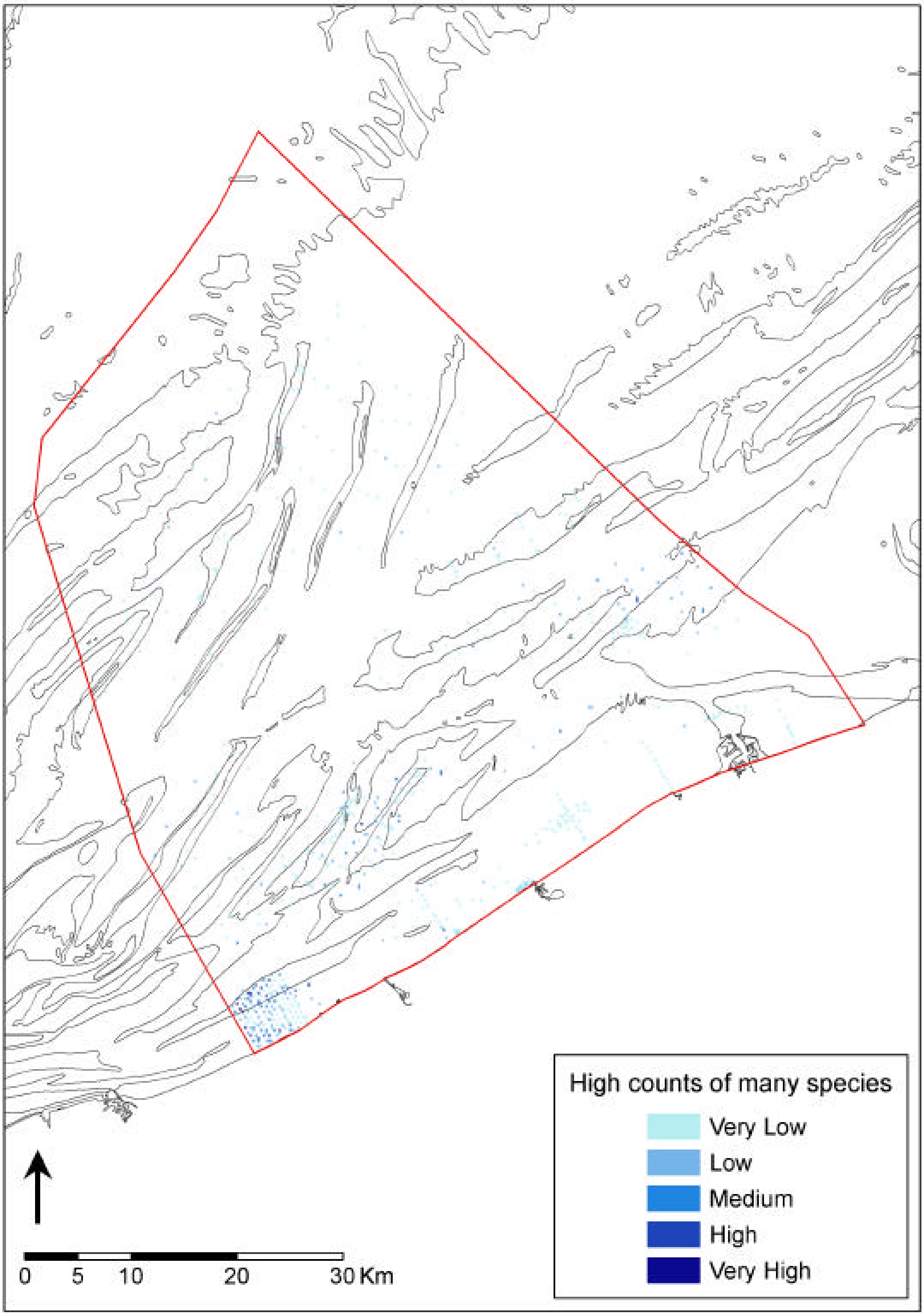


## *S. Overview of the distribution of the sampling effort for macrobenthos on the BPNS*

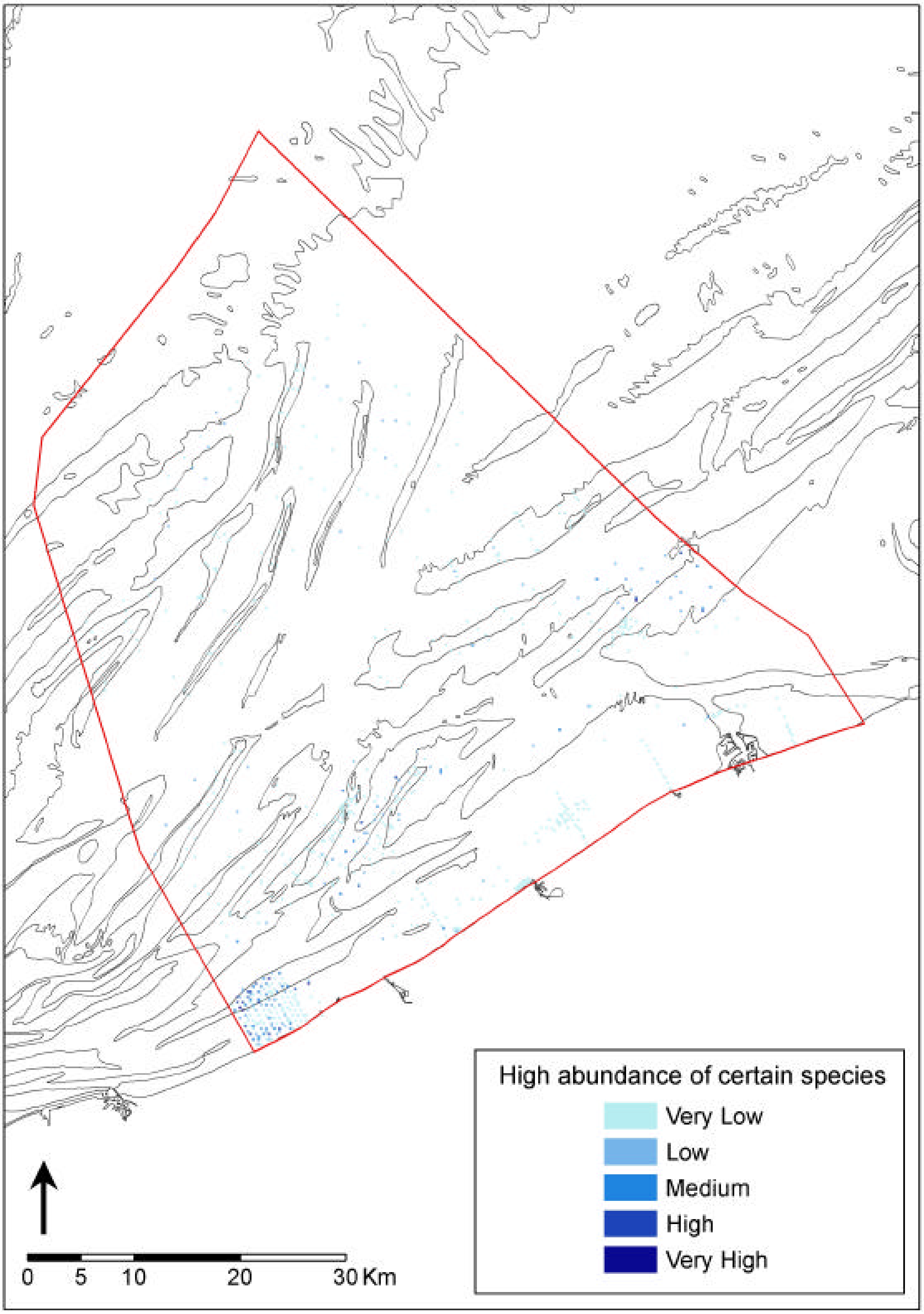


## *T. Maps of the assessment questions for macrobenthos*

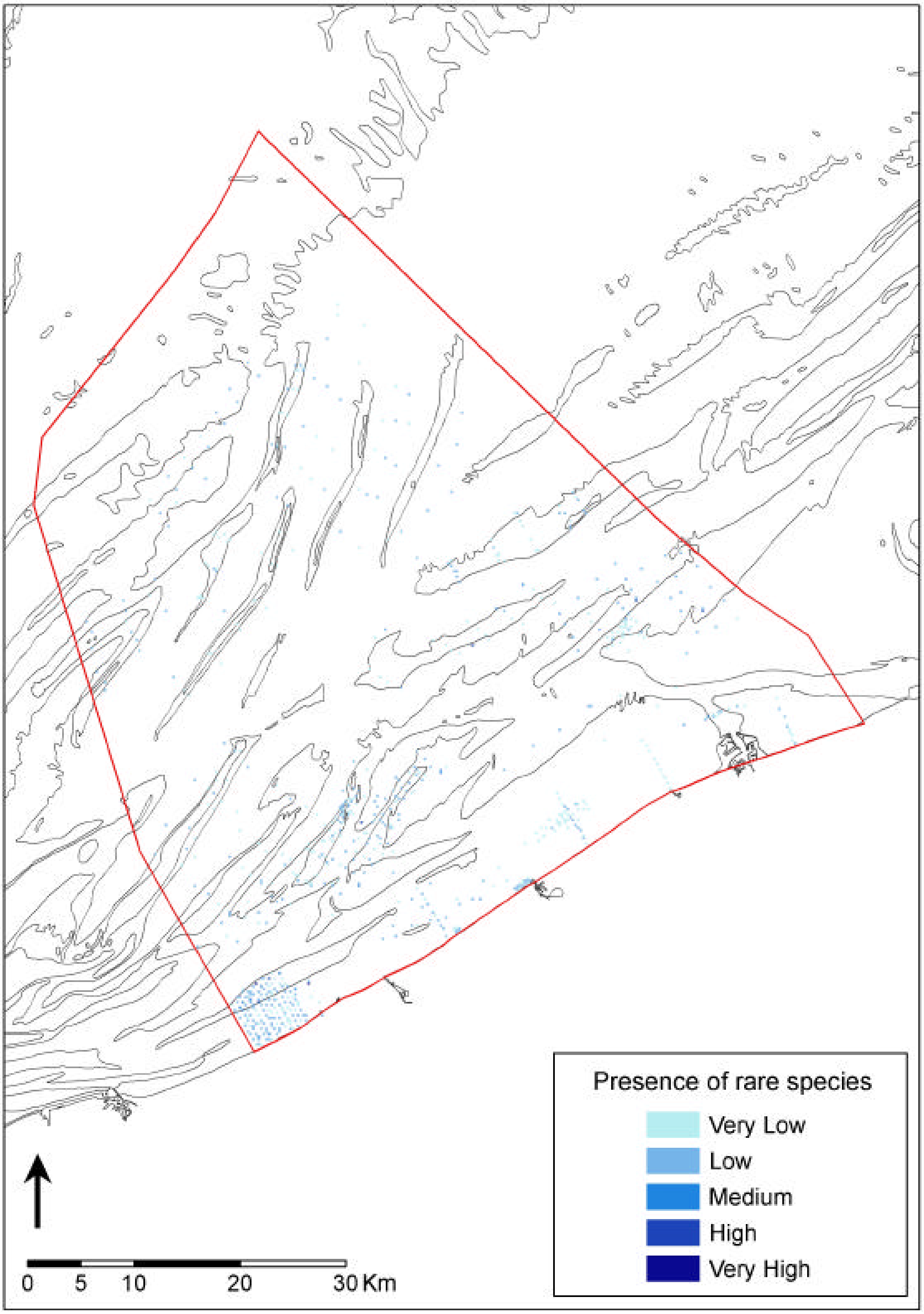
### 1. Question 1: Is the subarea characterized by high counts of many species?



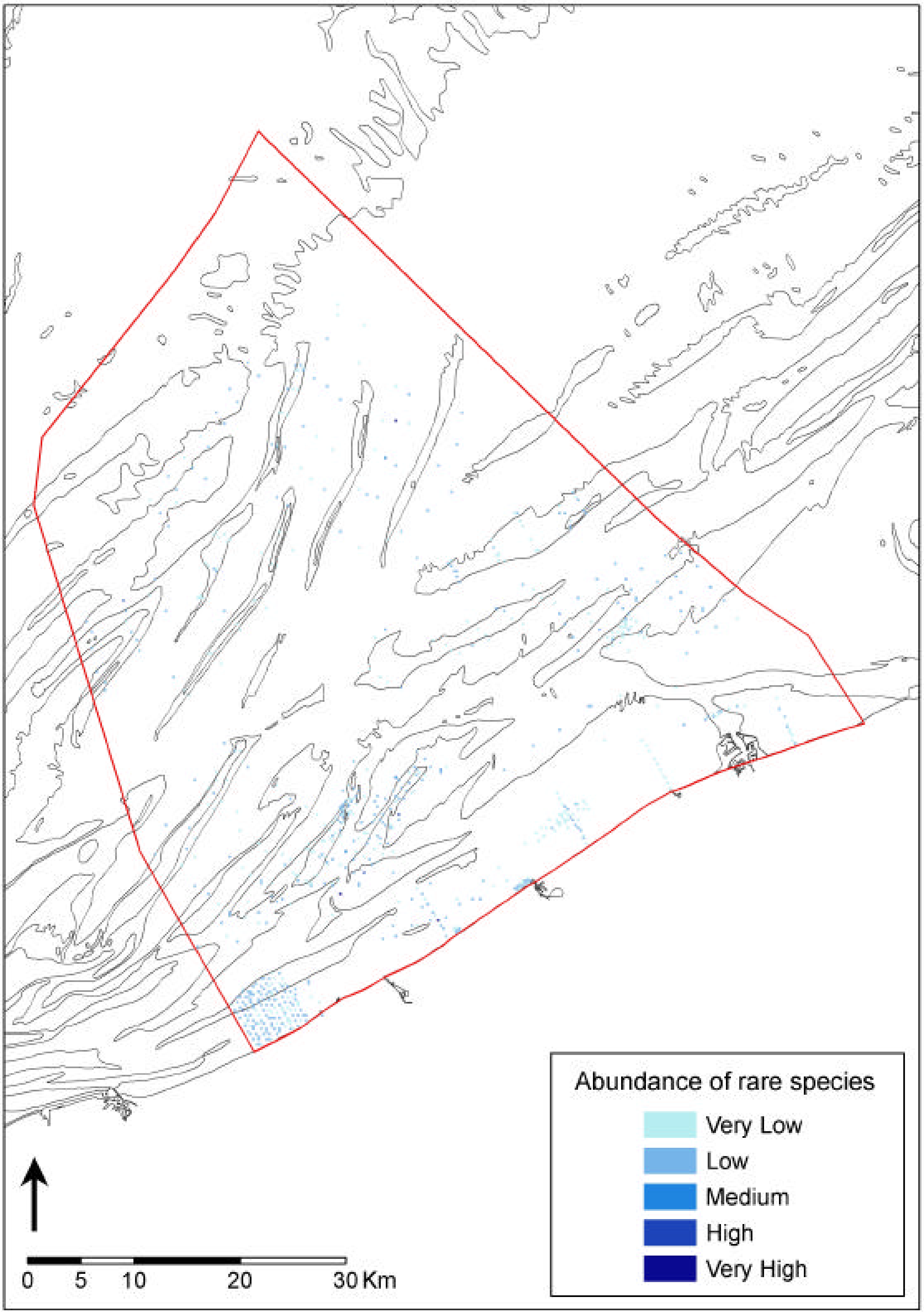
## 2. Question 2: Is the abundance of a certain species very high in the subarea?



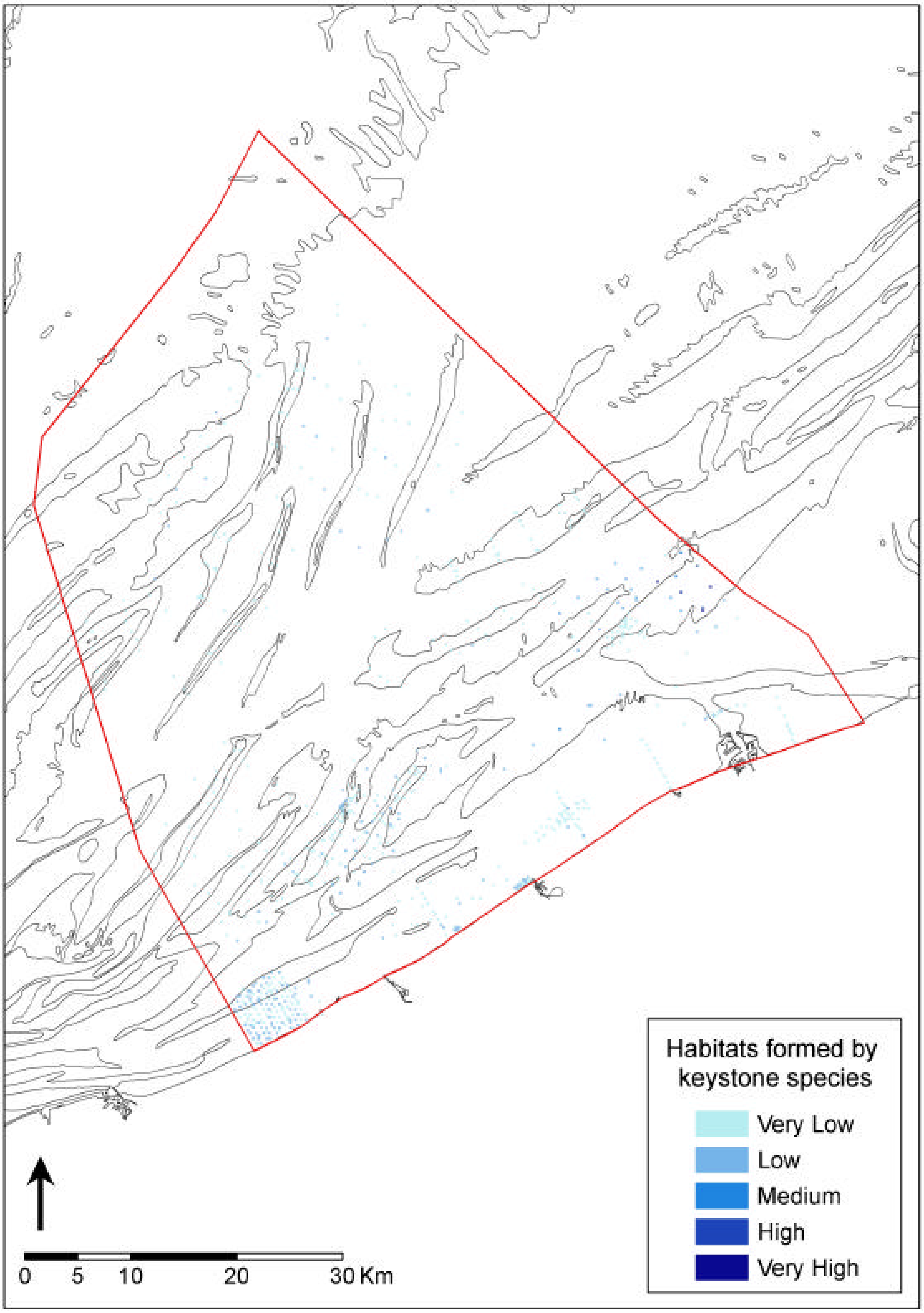
## 3. Question 3: Is the subarea characterized by the presence of many rare species?



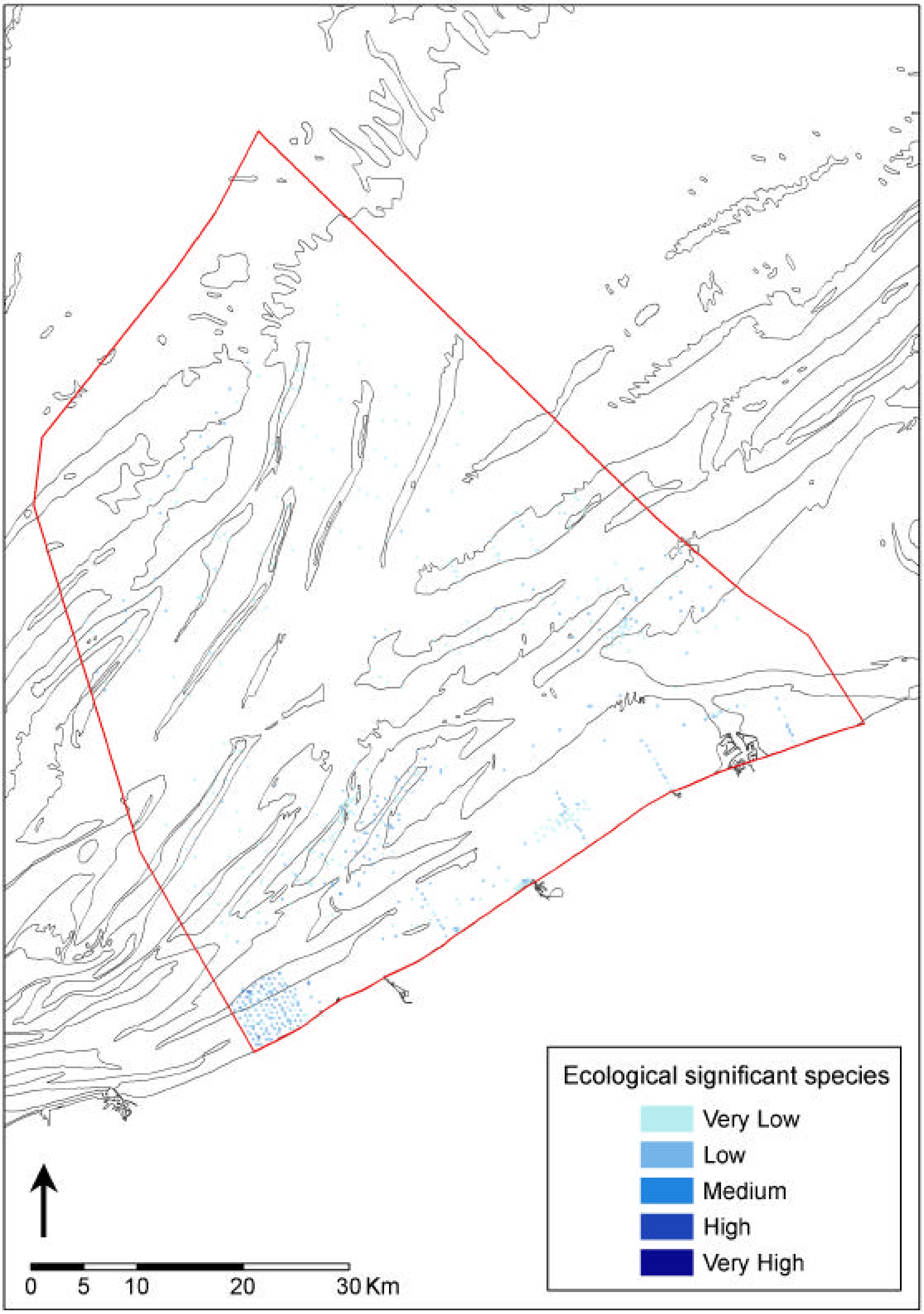
## 4. Question 4: Is the abundance of rare species high in the subarea?



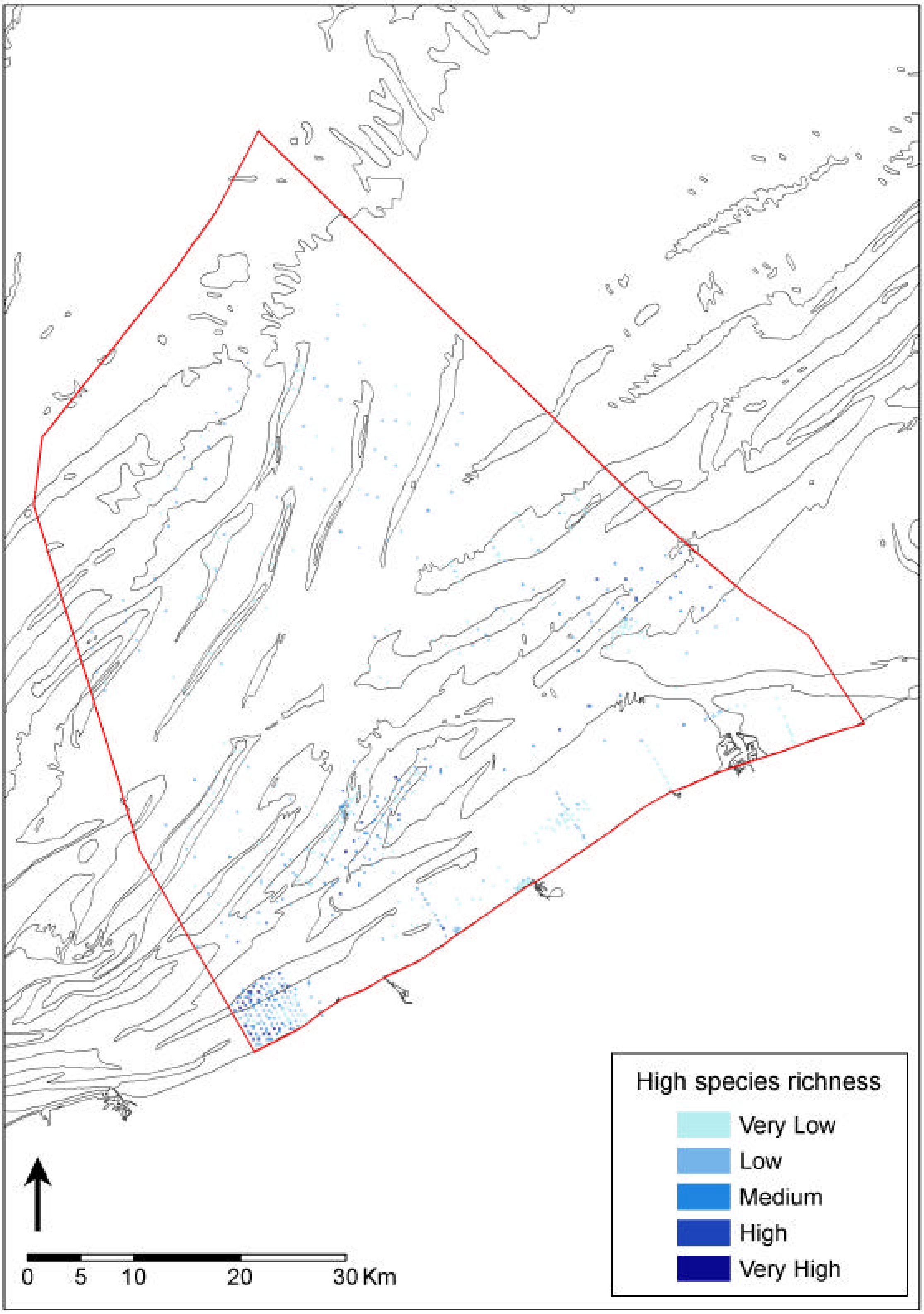
## 5. Question 5: Is the abundance habitat-forming species high in the subarea?



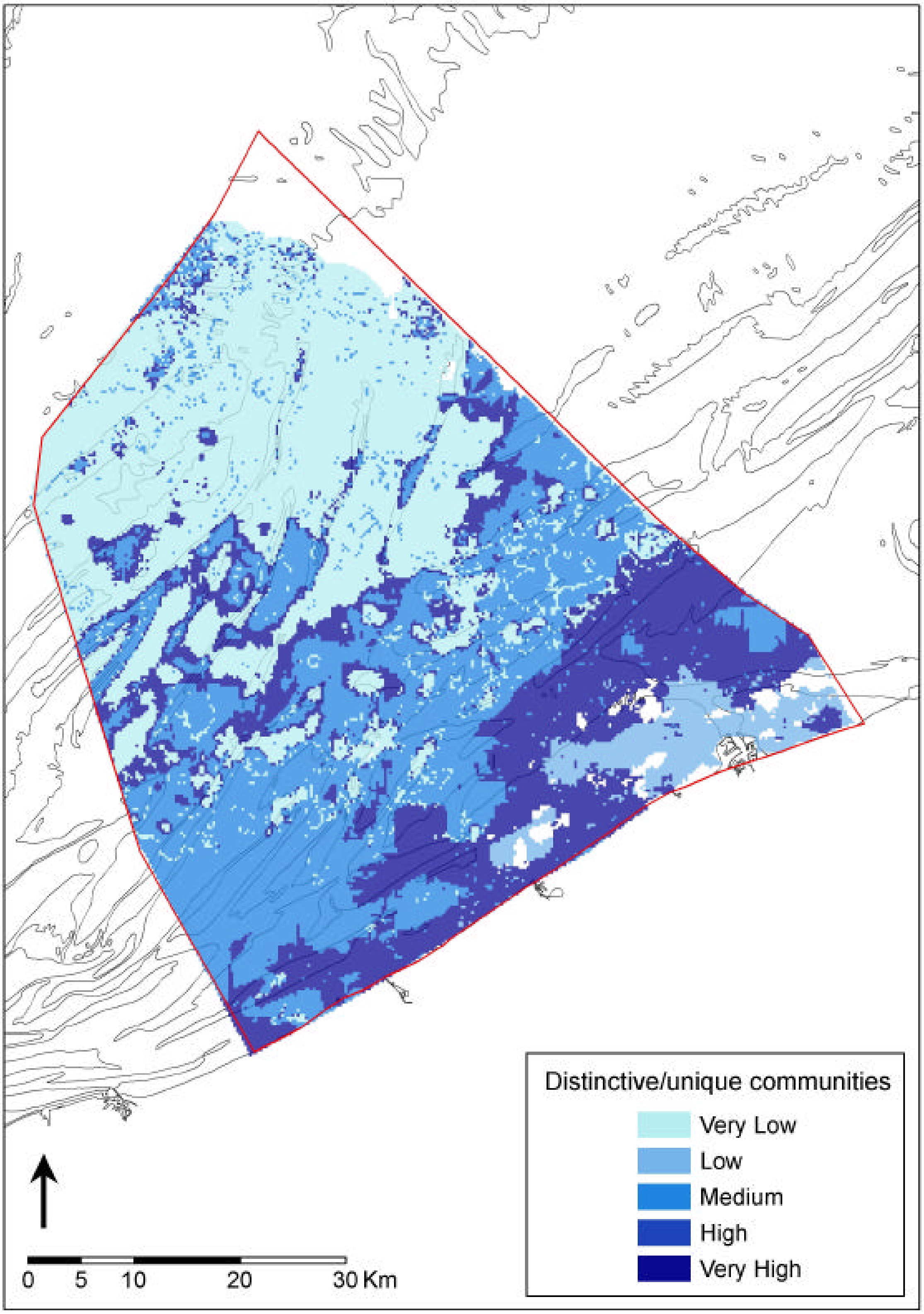
## 6. Question 6: Is the abundance of ecologically significant species high in the subarea?



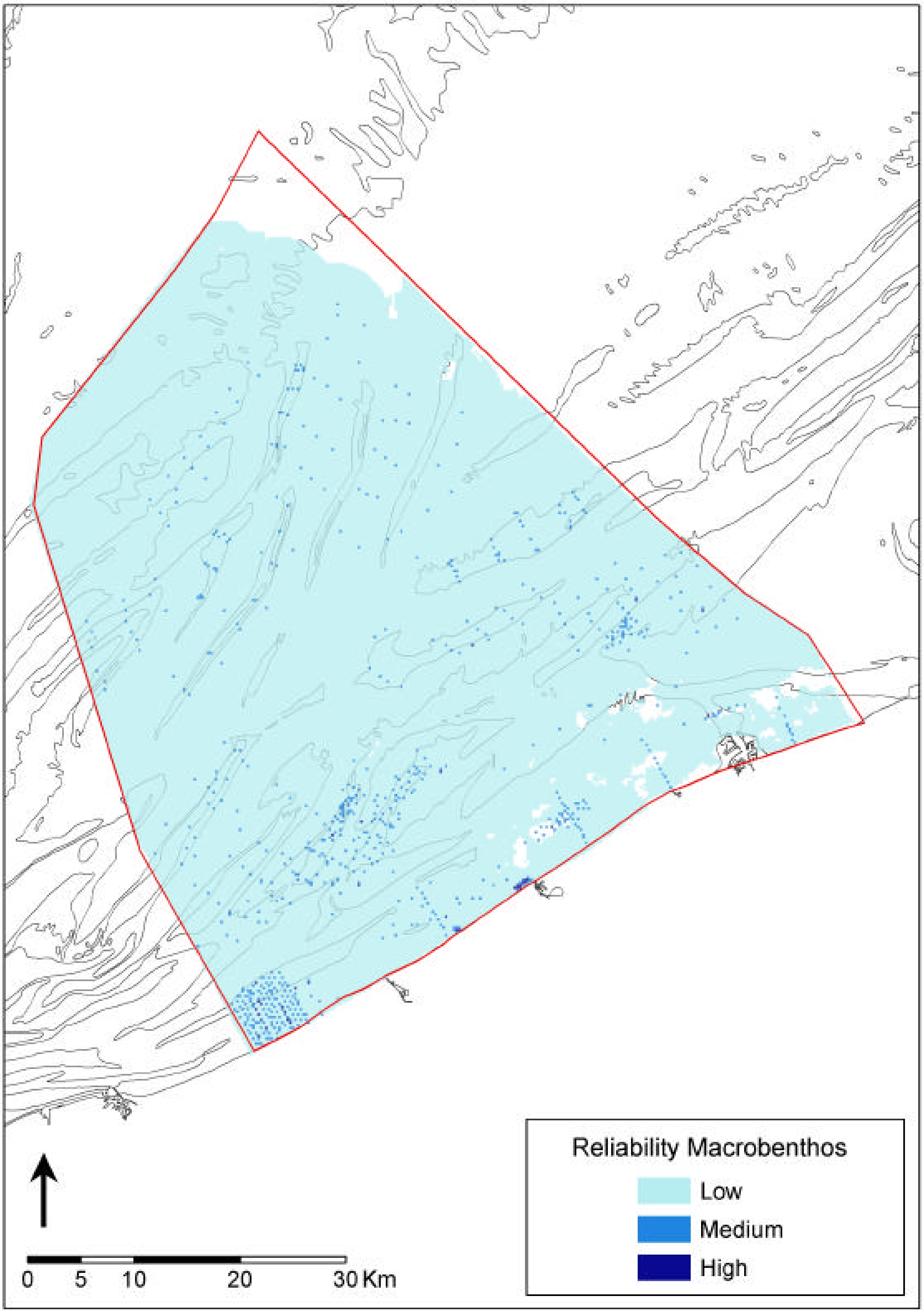
## 7. Question 7: Is the species richness in the subarea high?



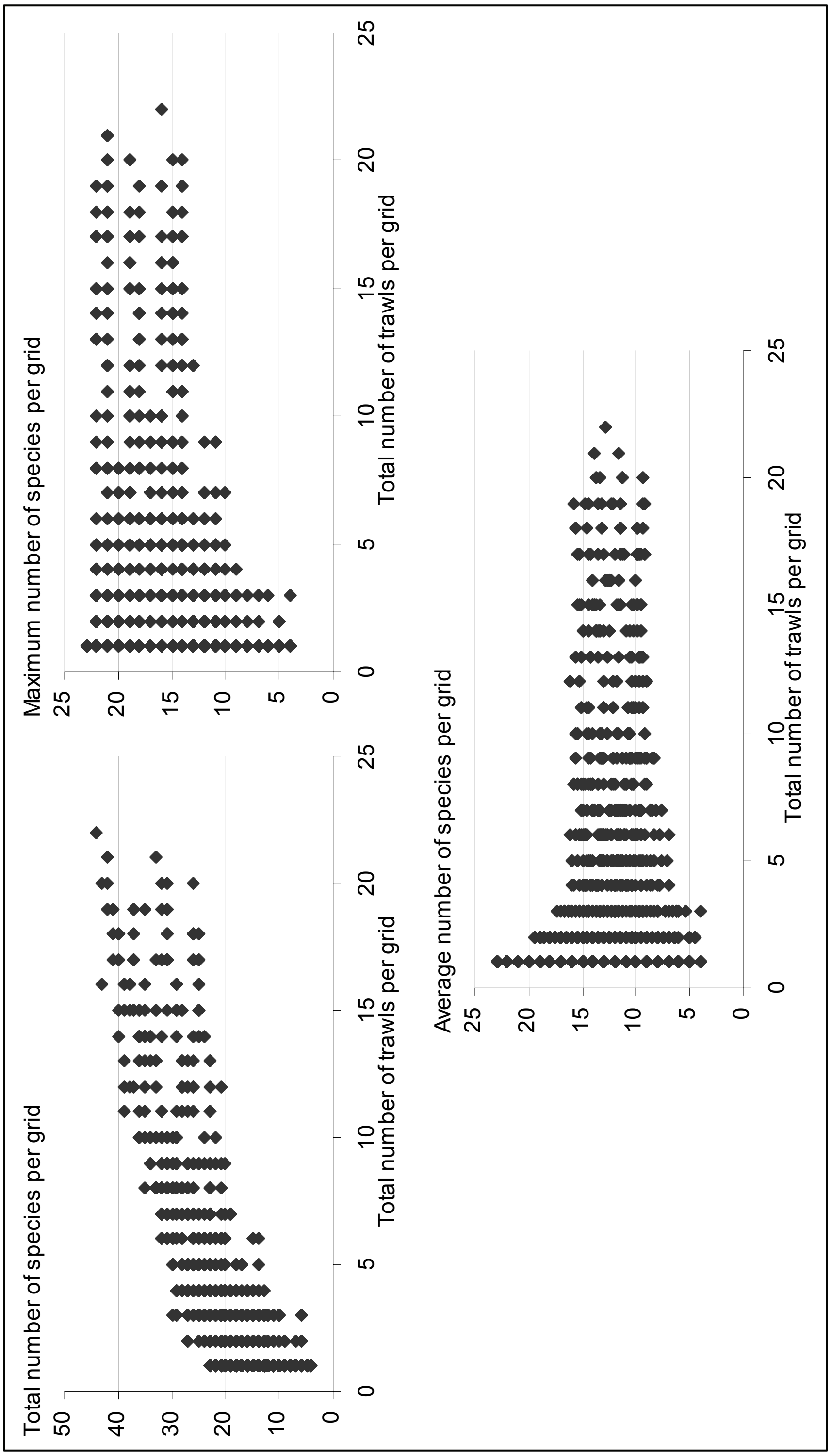
## 8. Question 8: Are there distinctive/unique communities present in the subarea?



## *U. Map showing the reliability of the macrobenthos valuation*

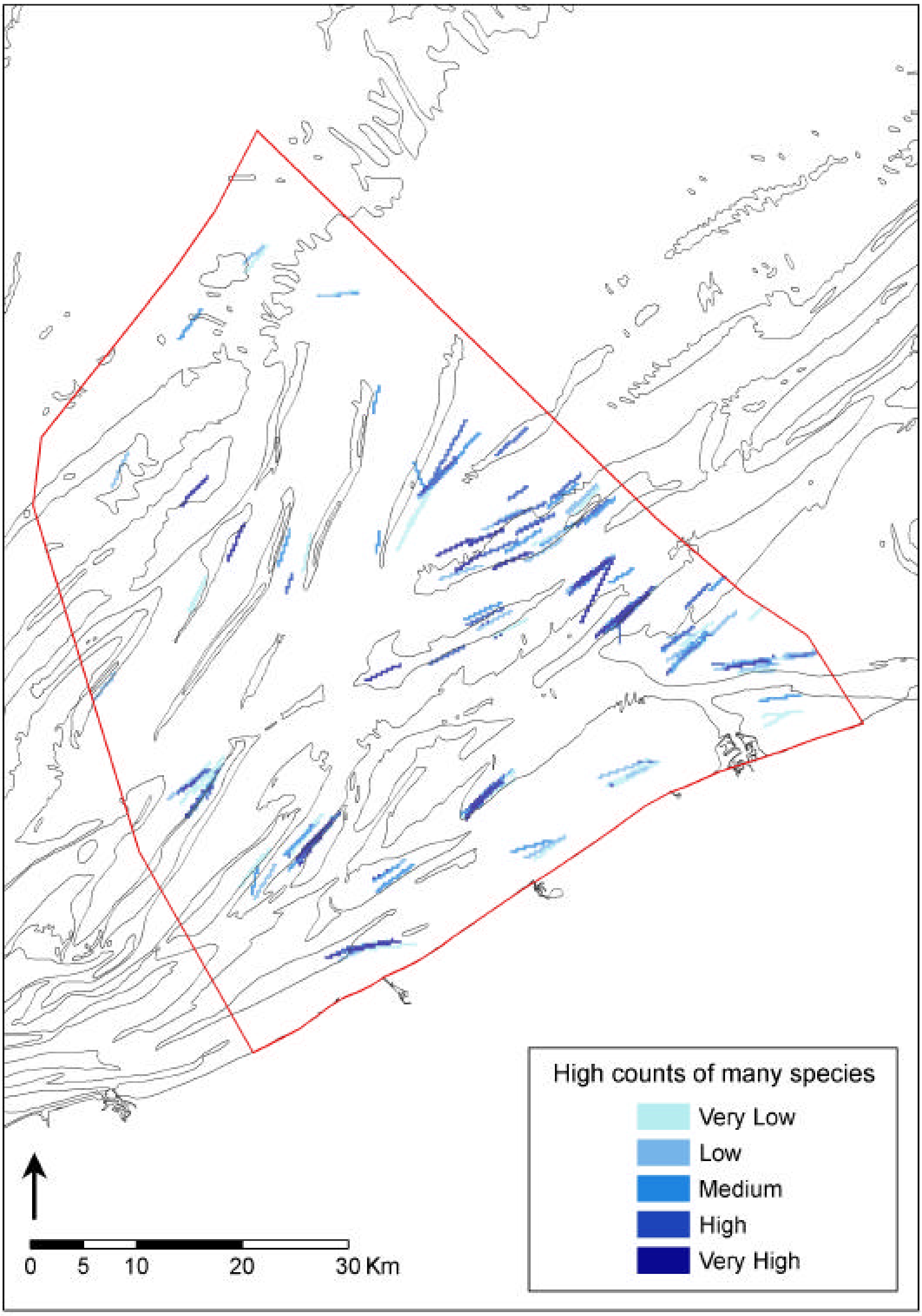


### *V. Relation between the sampling effort and the total, maximum and average species richness for the epibenthos.*

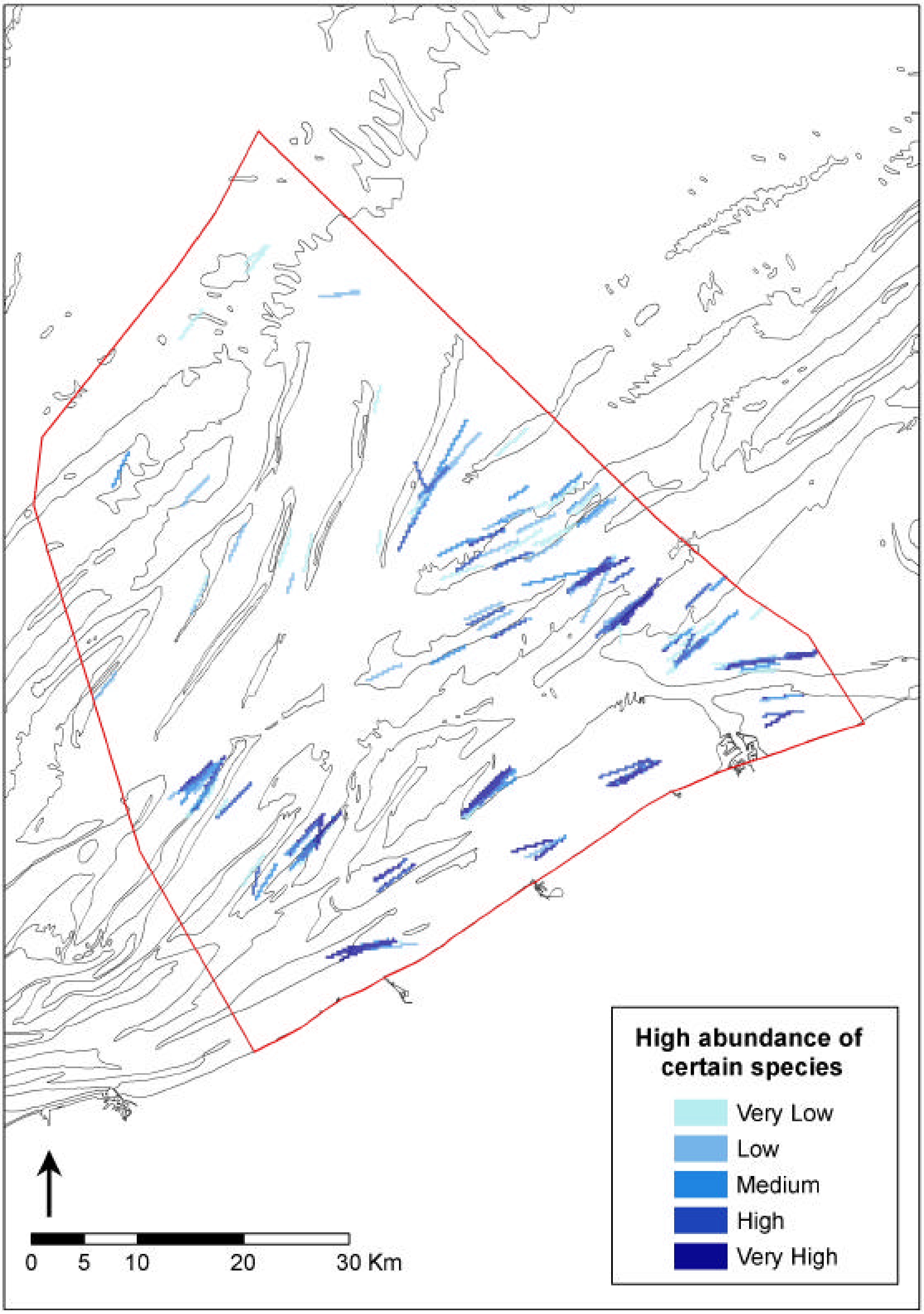


## *W. Maps of the assessment questions for epibenthos*

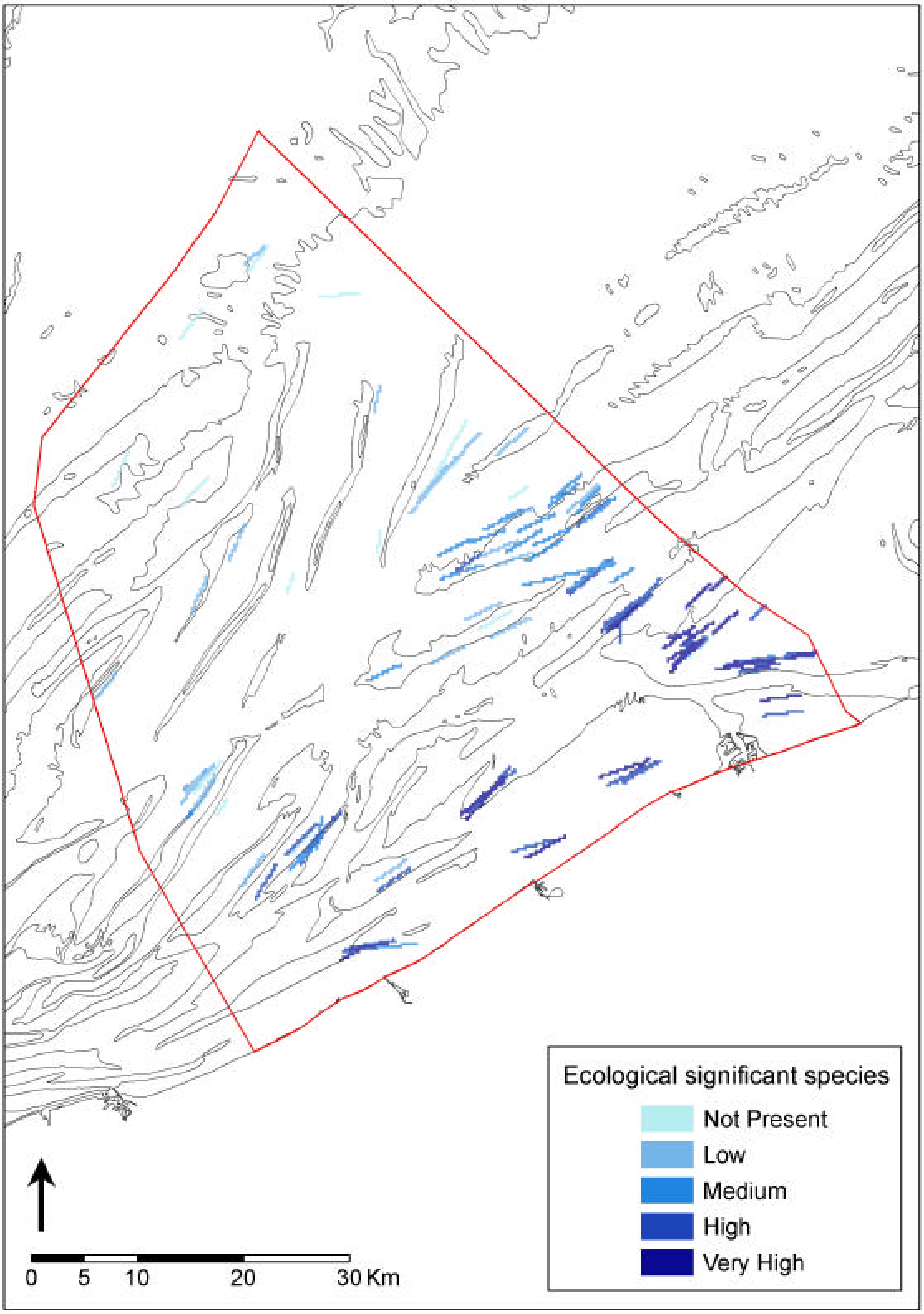
### 1. Question 1: Is the subarea characterized by high counts of many species?



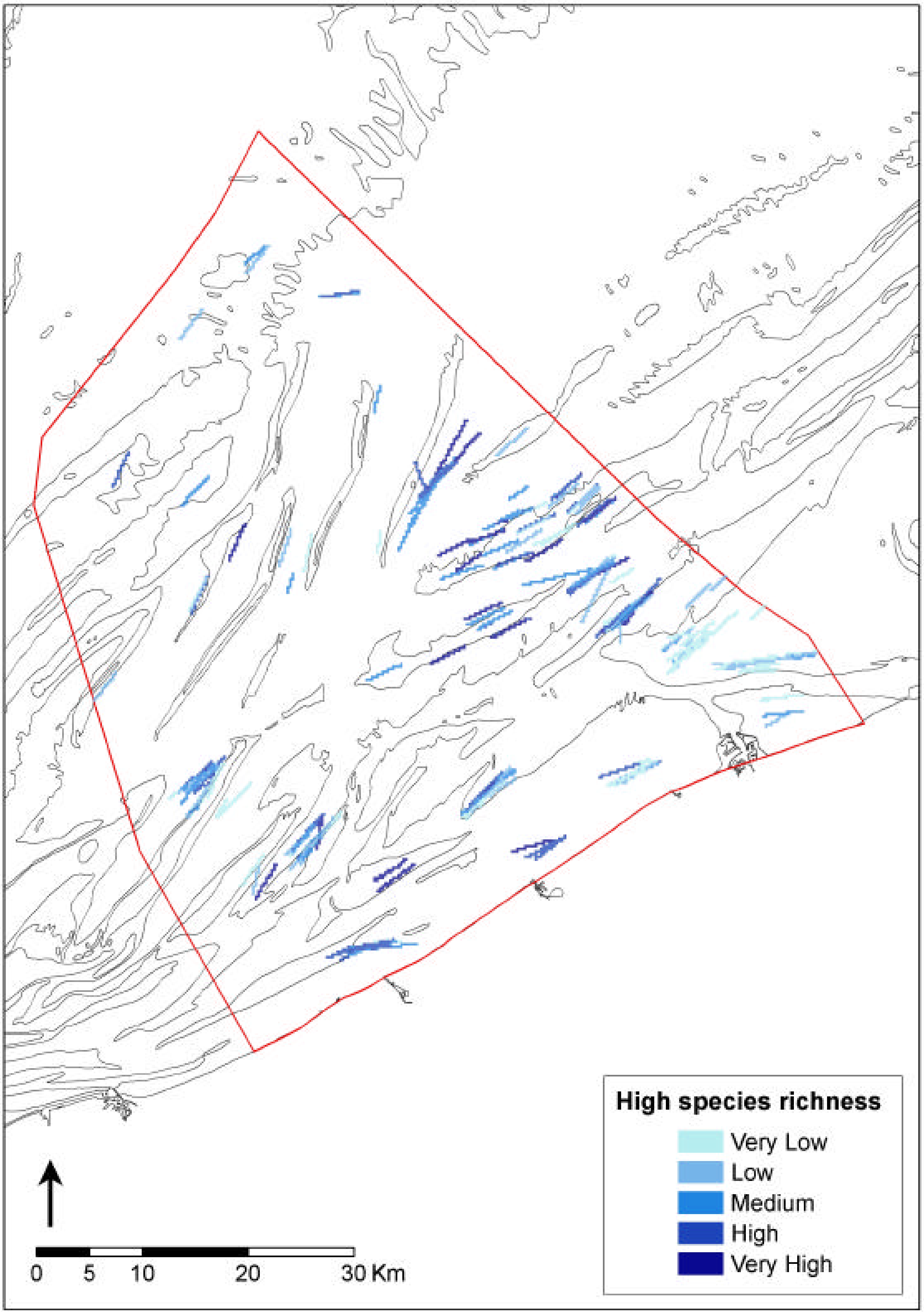
## 2. Question 2: Is the abundance of a certain species very high in the subarea?



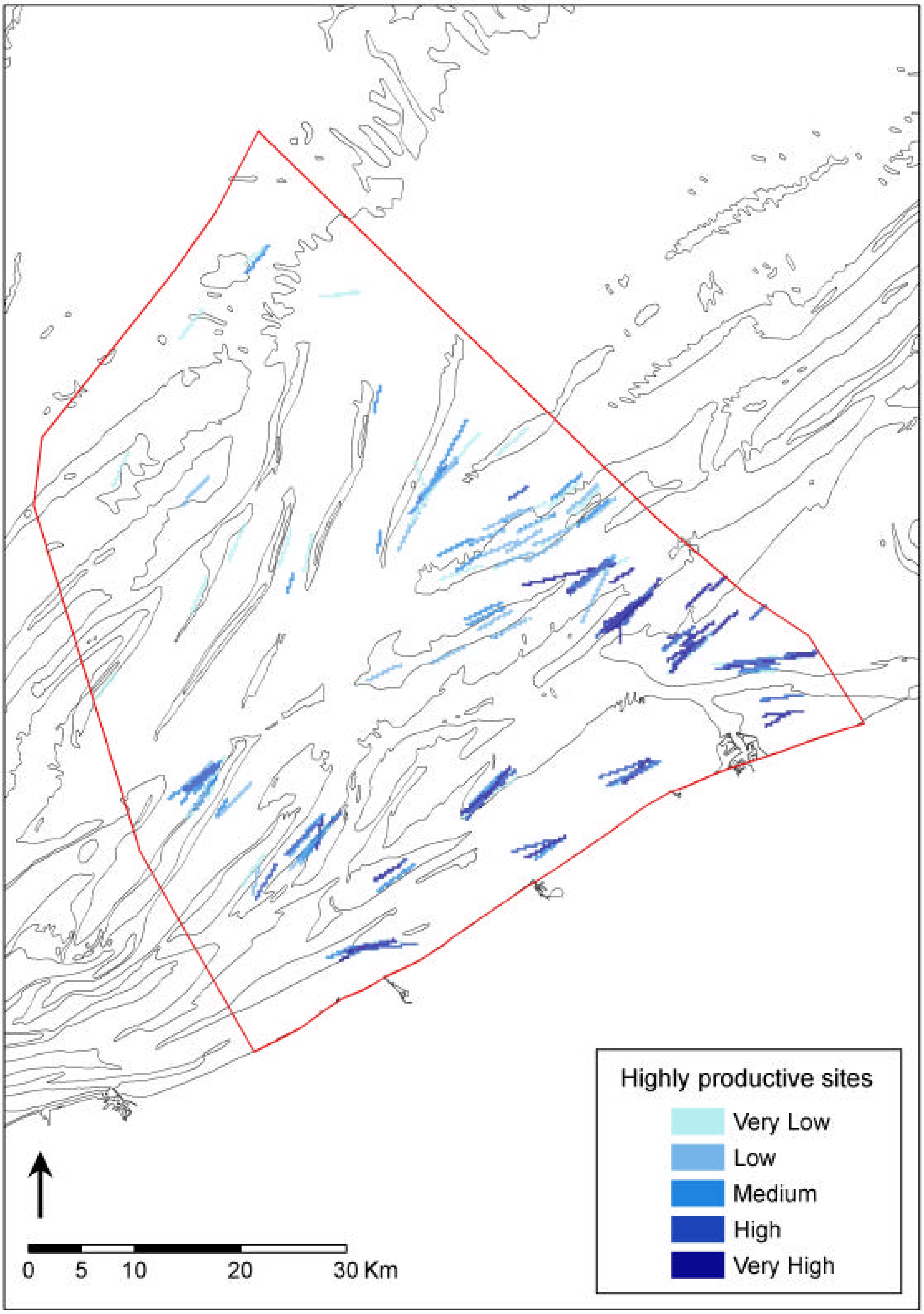
## 3. Question 3: Is the abundance of ecologically significant species high in the subarea?



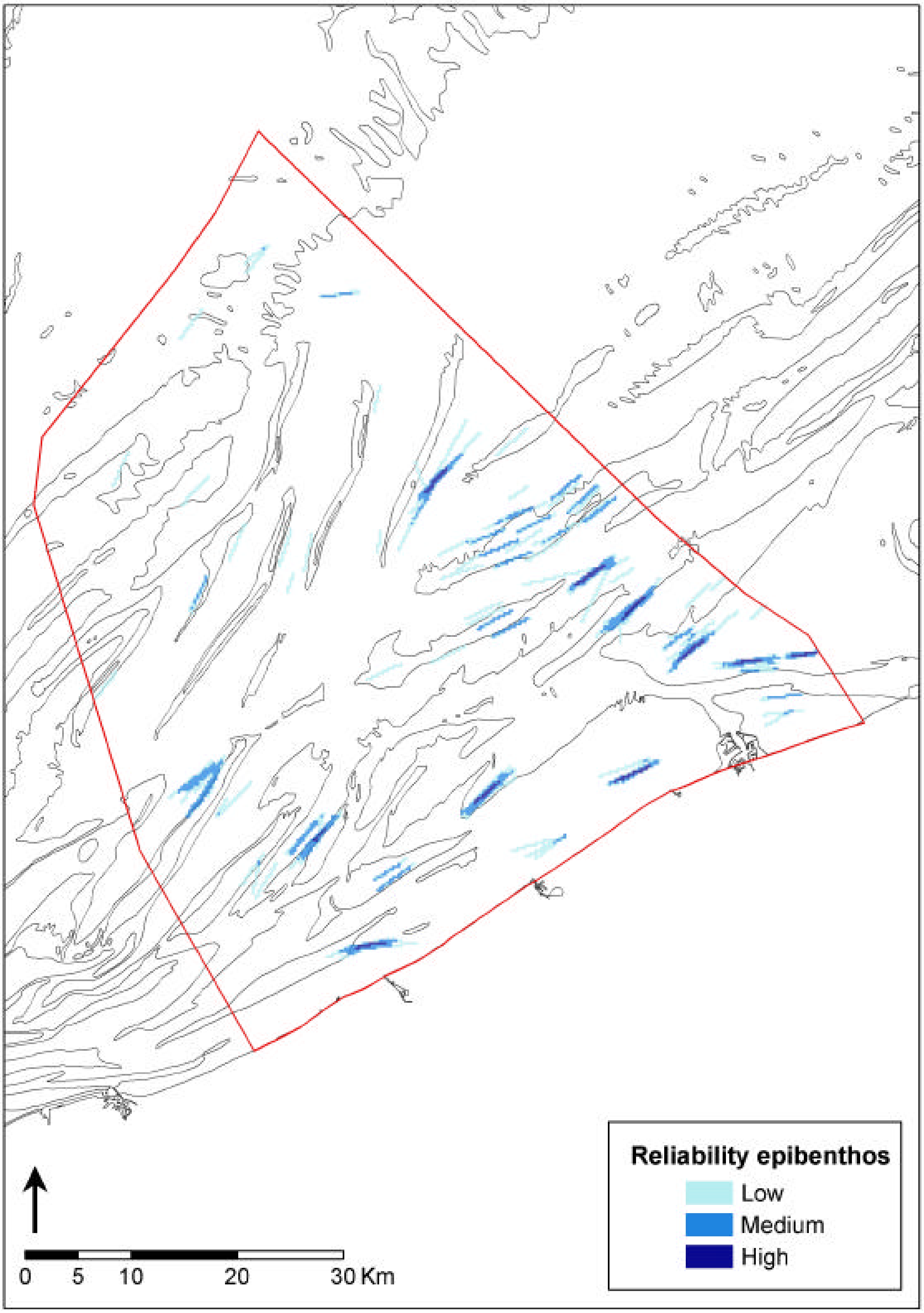
## 4. Question 4: Is the species richness in the subarea high?



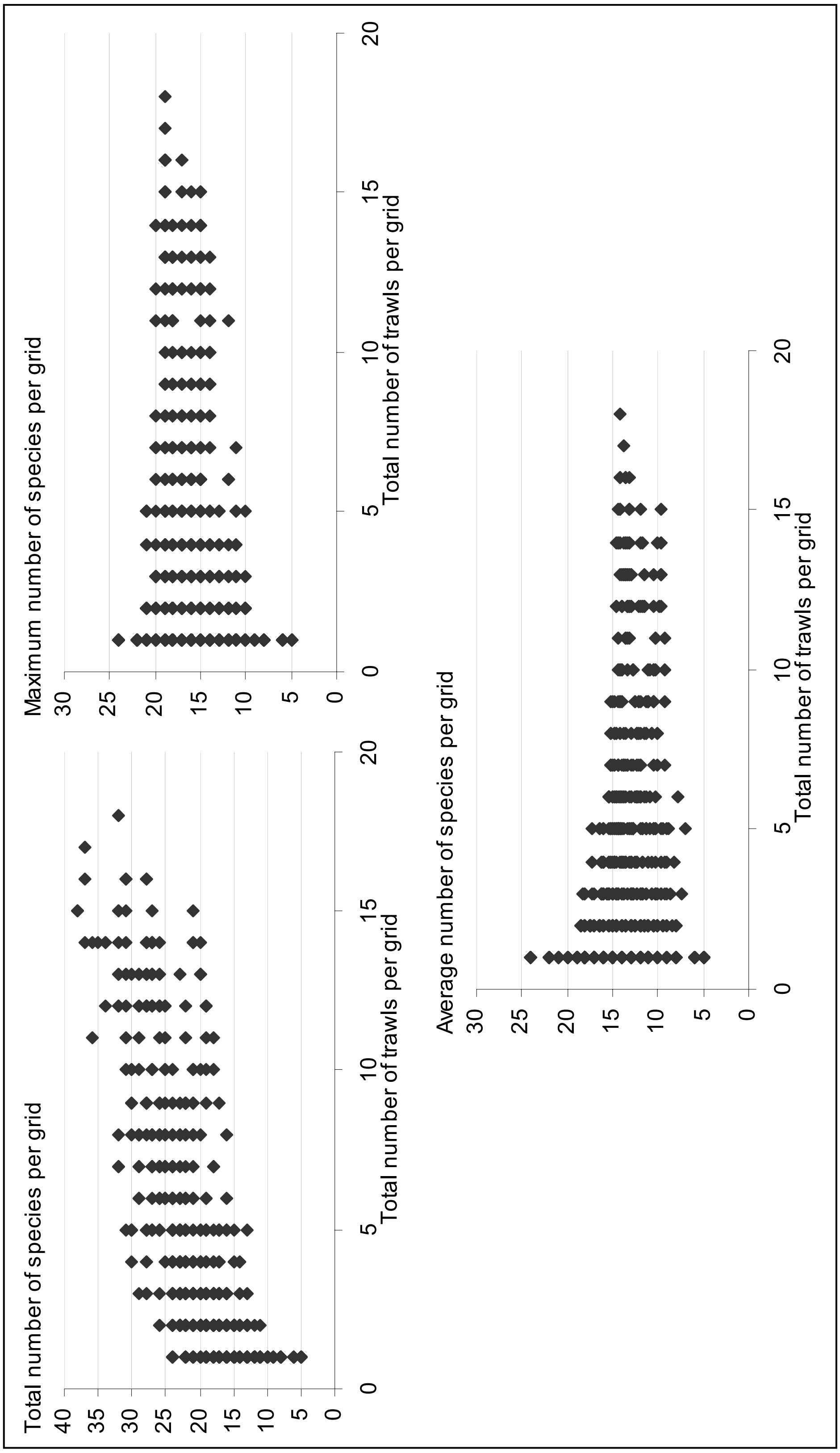
## 5. Question 5: Is the subarea highly productive?



***X. Map showing the reliability of the epibenthos valuation.***

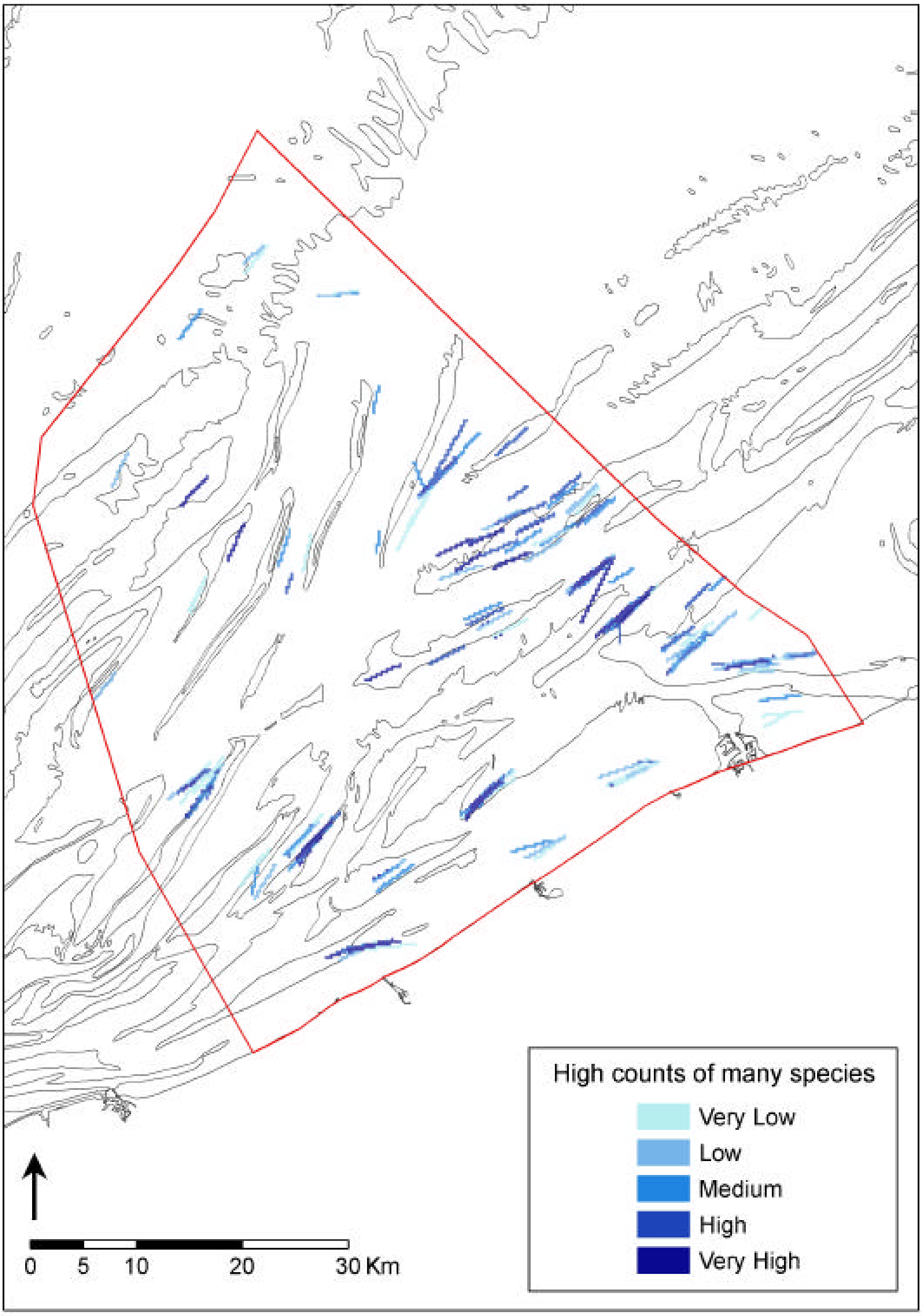


***Y. Relation between the sampling effort and the total, maximum and average species richness for the demersal fish.***

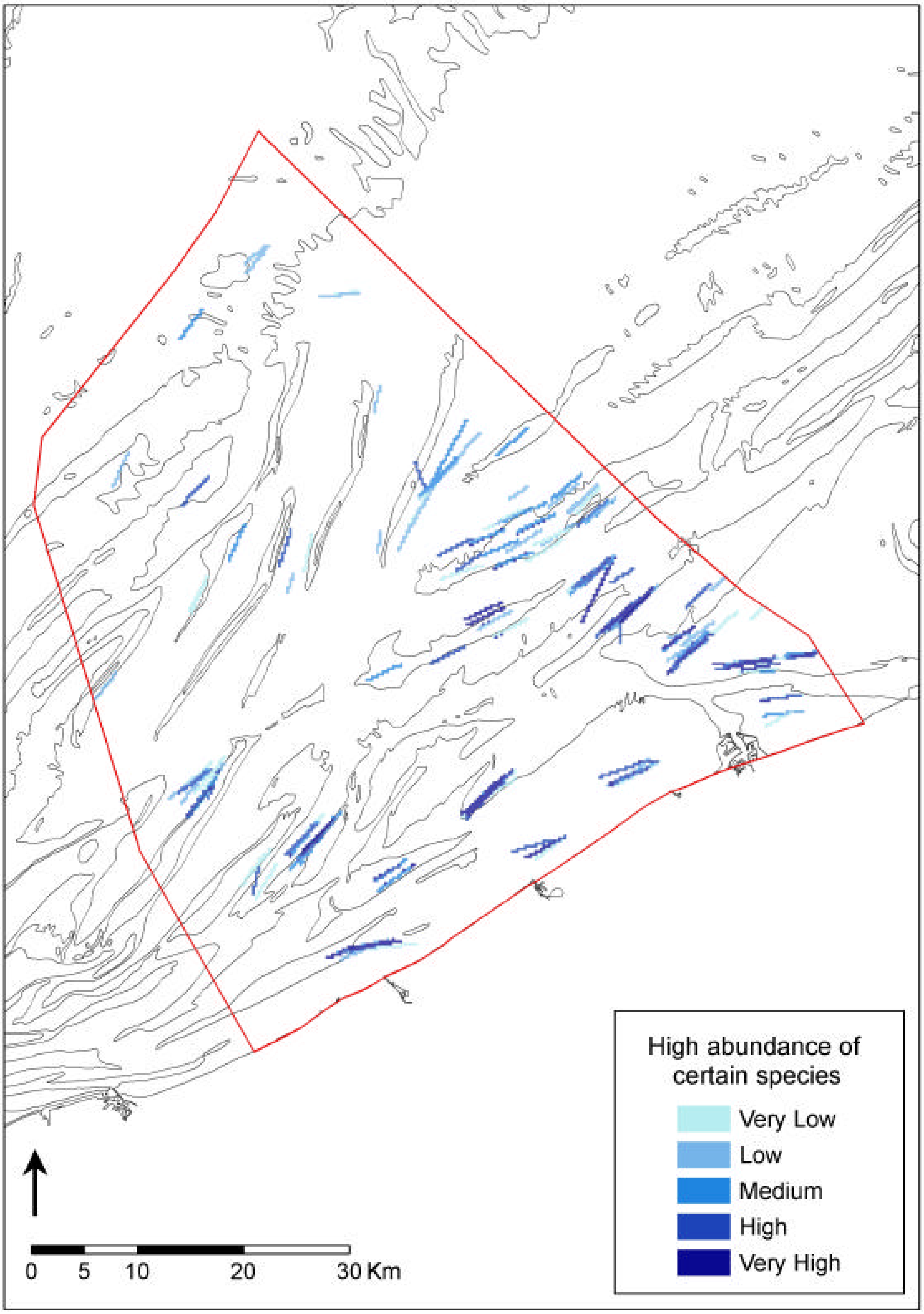


## Z. *Maps of the assessment questions for demersal fish*

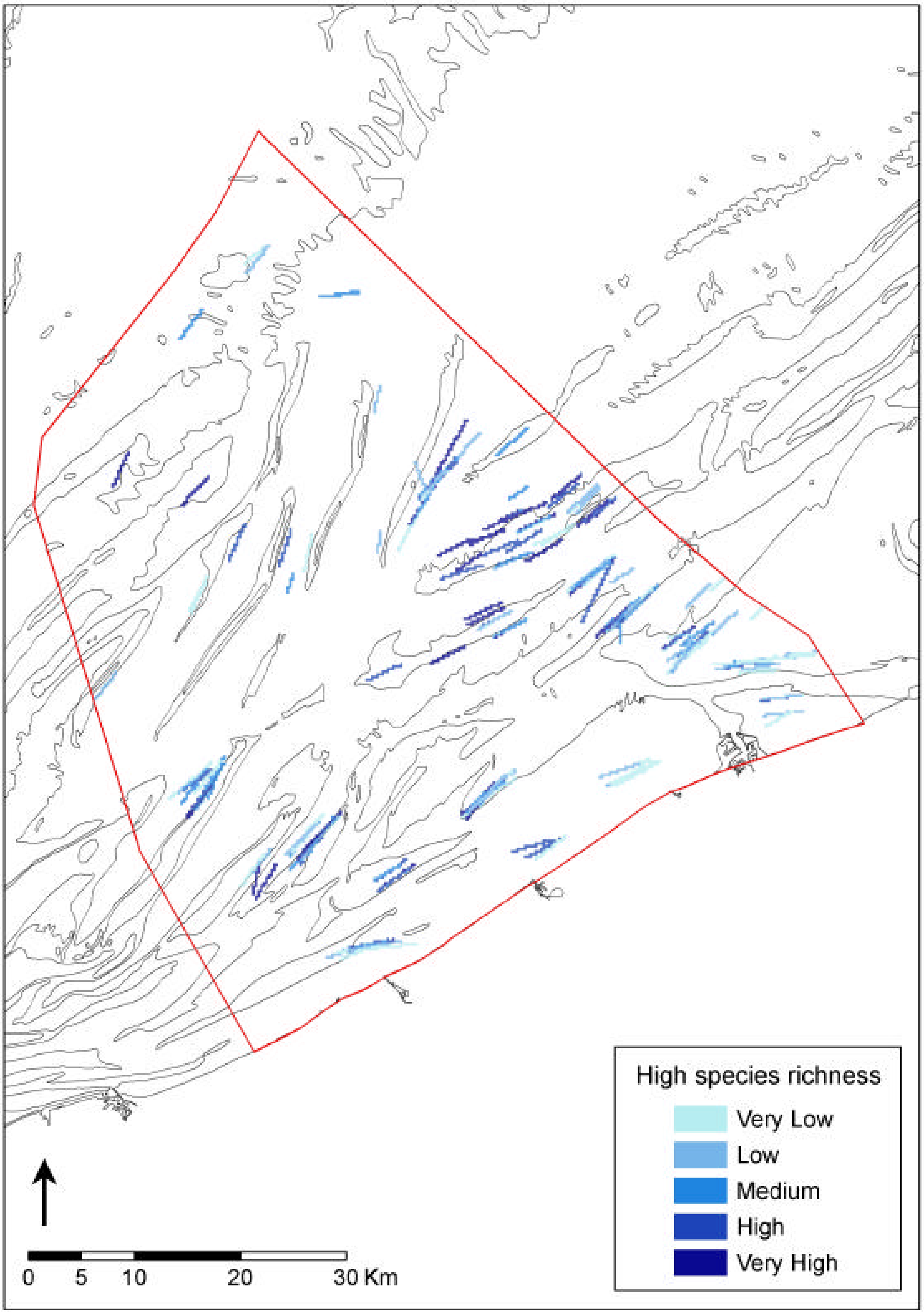
### 1. Question 1: Is the subarea characterized by high counts of many species?



## 2. Question 2: Is the abundance of a certain species very high in the subarea?



## 3. Question 3: Is the species richness in the subarea high?



## *AA. Map showing the reliability of the demersal fish valuation*